1991-12

Parametric cost estimation for amphibious assault vehicle's life cycle cost

Peters, Norman L.

Monterey, California. Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

PARAMERIC COST ESTIMATION FOR AMPHIBIOUS ASSAULT VEHICLE'S LIFE CYCLE COSTS

by

Norman L. Peters

December, 1991

Thesis Advisor: Joseph G. San Miguel

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

- 1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED
- 1b RESTRICTIVE MARKINGS:
- 2a SECURITY CLASSIFICATION AUTHORITY: Multiple Sources
- 2b DECLASSIFICATION / DOWNGRADING SCHEDULE:
- 3 DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited
- 4 PERFORMING ORGANIZATION REPORT NUMBER(S):
- 5 MONITORING ORGANIZATION REPORT NUMBER(S):
- 6a NAME OF PERFORMING ORGANIZATION: Naval Postgraduate School
- 6b OFFICE SYMBOL (If applicable):
- 7a NAME OF MONITORING ORGANIZATION: Naval Postgraduate School
- 6c ADDRESS (City, State, and ZIP Code): Monterey, CA 93943-5000
- 7b ADDRESS (City, State, and ZIP Code): Monterey, CA 93943-5000
- 8a NAME OF FUNDING / SPONSORING ORGANIZATION:
- 8b OFFICE SYMBOL (If applicable):
- 9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:
- 8c ADDRESS (City, State, and ZIP Code):
- 10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO
- 11 TITLE (Include Security Classification): PARAMETRIC COST ESTIMATION FOR AMPHIBIOUS ASSAULT VEHICLE'S LIFE CYCLE COSTS (UNCLASS)
- 12 PERSONAL AUTHOR(S): Peters, Norman L.
- 13a TYPE OF REPORT: Master's Thesis
- 13b TIME COVERED: FROM ______ TO ______
- 14 DATE OF REPORT (Year, Month, Day): 1991, December
- 15 PAGE COUNT: 131
- 16 SUPPLEMENTARY NOTATION: The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.
- 17 COSATI CODES: FIELD / GROUP / SUB-GROUP
- 18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Cost Estimating Relatioships, Life Cycle Costs, Advanced Amphibious Assault Vehicle
- 19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This thesis investigates the need to predict life cycle cost in the most effective and efficient manner through the development of cost estimating relationships (CERs) using only performance input parameters. Utilizing statistical software especially developed for program managers, parametric cost estimating relationship module (PACER), CERs were developed and then evaluated for statistical soundness. The object of this study was to develop a means by which the program manager could estimate fairly accurately total life cycle costs. With this information in hand, the program manager could determine if a weapon system is affordable early in the acquisition process.

The result of this study was the derivation of three predictive models that relate cost to required performance parameters. Based solely upon performance requirements, a relationship between cost and required performance

- 20 DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS
- 21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
- 22a NAME OF RESPONSIBLE INDIVIDUAL: Joseph G. San Miguel
- 22b TELEPHONE (Include Area Code): 408-646-2187
- 22c OFFICE SYMBOL: AS/SM

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE Unclassified

S/N 0102-LF-014-6603

was established and their impact upon life cycle costs.

Approved for public release; distribution is unlimited.

Parametric Cost Estimation for Amphibious Assault Vehicle's Life Cycle Cost

by

Norman L. Peters
Captain, United States Marine Corps
B.S., U.S. Naval Academy, 1985

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 1991

ABSTRACT

This thesis investigates the need to predict life cycle cost in the most effective and efficient manner through the development of cost estimating relationships (CERs) using only performance input parameters. Utilizing statistical software especially developed for program managers, parametric cost estimating relationship module (PACER), CERs were developed and then evaluated for statistical soundness. The object of this study was to develop a means by which the program manager could estimate fairly accurately total life cycle costs. With this information in hand, the program manager could determine if a weapon system is affordable early in the acquisition process.

The result of this study was the derivation of three predictive models that relate cost to required performance parameters. Based solely upon performance requirements, a relationship between cost and required performance was established and their impact upon life cycle costs.

TABLE OF CONTENTS

I. INTRODUCTION

A. OVERVIEW

The fall of the Berlin Wall signalled an end to the cold war, and an uncontrollable federal budget deficit seeking new heights, the Department of Defense's budgetary practices have come under extraordinary political oversight. The era of "Defense Reduction" has begun, and by the year 1995, one third of the present day operating forces have been forecasted to be dissolved (Aaron and others, 1990). A reduction in both budget authority and outlays will occur across all defense categories. The emphasize will be to spend money wisely the first time, especially when estimating costs for procurement of new weapon systems. Major acquisitions are coming under intense congressional oversight to insure that they are affordable.

Who is responsible within the Department of Defense (DOD) for weapon system acquisition? The primary advocate for any weapon system program is the program manager (PM). The PM must understand the military need for his particular system and become intimately involved with its evolution. This evolution involves a series of minor decisions that may have a major impact upon the program. Therefore, the PM must understand and appreciate the implication of each and every

trade-off decision that is made. He alone is responsible and accountable for the success or failure of the program (Fitzgerald, 1990).

The dire need to maintain new technological advance weapon systems will only increase but, the costs of these advances will be severely scrutinized. This is the problem facing the Marine Corps' amphibious assault vehicle program. New requirements to be able to launch an amphibious assault from over-the-horizon (OTH) has come of age (Marine Corps Gazette, July 1991). Presently, the Marine Corps conducts amphibious assaults with the amphibious assault vehicle, AAV7A1. This amphibious assault vehicle is the last of a long line of procurement stemming from the development of the LVPT-7 Amphibian Tractor Program during the early 1970s. The AAV7A1 does not have the nautical range nor land speed required to conduct future offensive operations into the next century.

The current AAV7A1 will reach the end of its service life shortly after the turn of the century in year 2000 (Kusek, 1991). Several possible replacements have been designated as the Advanced Amphibious Assault Vehicle (AAAV) and are currently passing milestone one of the acquisition process. The need to develop an effective tool to predict accurate life cycle costs is essential to the successful development of the AAAV. The past track record of the LVPT-7 Amphibian Tractor Program proved that combat effective hardware could be delivered on schedule and, within funded ceilings (Bahnmaier,

1974). The need to continue this tradition for the AAAV can be obtained through the use of parametric cost analysis techniques which can further used to develop Cost Estimating Relationships (CERs) to predict accurate life cycle costs.

What is life cycle cost? As defined, life cycle costs (LCC) is the total cost to the government to acquire and own a system. This includes cost of development, procurement, operation and support (Fitzgerald, 1990). In this study life cycle costs will be broken down into three distinct elements: Research, Development, Testing, and Evaluation (RDT&E) Costs; Procurement (Proc.) Costs; Operation and Support (O&S) Costs. The LCC formula that is applied throughout this study is:

$$LCC = RDT\&E + Proc. + O\&S$$

The stage is set with the development of new technology during a time of considerable budget restraint. On the one hand, there exists the natural development of OTH amphibious landings, and on the other the development of technology that presently does not exist. The difference between successfully fielding or fraudulently floundering will be the ability to predict the costs of new technological advances. The mission has always been paramount but, in these days of budget constraints, costs will the most significant determining factor.

B. OBJECTIVES OF RESEARCH

The objectives of this study are to : (1) develop a Cost Estimation Relationship that will be able to reasonably predict the life cycle costs of the planned Advance Amphibious Assault Vehicle, (2) define the costs associated with technological advancements in meeting mission requirement of over-the-horizon (OTH) and sustained mobile combat operations ashore.

C. RESEARCH QUESTIONS

To support this study's research the following primary question was proposed: What will be the anticipated life cycle costs of the follow on to the Amphibious Assault Vehicle, AAV7R1?

In support to this question, the following subsidiary questions were addressed:

1. What will be the trade off effect on increasing range and speed upon the life cycle costs of the AAAV?

2. Does the developed Cost Estimation Relationship (CER) meet acceptable statistical test model parameters in regard to; Coefficients of Determination (R^2), Coefficient of Variation (CV), Standard Error (SE), t-ratio test, and the F-statistic?

D. RESEARCH METHODOLOGY

Basic information presented in this study was obtained from: (1) current literature, (2) Defense Logistics Studies Information Exchange (DLSIE), (3) Defense Technical Information Center (DTIC), and (4) the Department of Defense

directives and instructions. The cost data was collected from many government agencies to include the program office responsible for development of the AAAV. Additional cost data was obtained from various references located in Knox Library at Naval Postgraduate School, Monterey, California. The development of CERs was done with statistical software package known as Parametric Cost Estimating Relationship Module (PACER) provided from the Defense Systems Management College at Fort Belvoir, Virginia.

The selection to use PACER was two folded. In the first place, the author of this study wanted to test the simplicity of the program since, it was originally conceived to be used by novice program managers with little or no statistical background. Secondly, this thesis can be used as a data base source document with specific PACER application which can aid in further evaluation of the software as it is developed.

E. SCOPE OF STUDY

The main thrust of this study will be the development of a cost estimation relationship that can be used to accurately predict the life cycle costs of the AAAV. The intent of this estimation is to aid DOD decision makers such as program managers with a summary of information depicting the cost tradeoff between the requirement of additional speed and range essential to the OTH amphibious operations in the development of the AAAV. Armed with this information, the decision maker

can better assess the present condition of the AAAV program in respect to present cost and future costs throughout the milestone process.

F. LIMITATIONS

The major element in using parametric analysis is data. Consequently, the validity of the data in conjunction with expanding technologies will determine the accuracy of the CER. For example, if the development of a CER was solely based upon historical costs alone, it can be misleading especially when considering the development of new technologies. The data used in this study tried to match similar technologies with projected requirements in order to achieve an accurate prediction of life cycle costs.

G. ASSUMPTIONS

It is assumed that the reader of this study has a basic understanding of the concepts dealing with parametric statistical analysis to include aforementioned statistical tests approaches.

H. ORGANIZATION OF STUDY

Chapter II describes the three approaches associated with parametric cost analysis. Chapter III develops CERs for further application to set parameters for the AAAV with application to four phases of parametric analysis; Data Collection, Data Analysis/Adjustment, Data Manipulation, and

CER Derivation. Chapter IV provides recommendations and concluding application upon the derived CER with remarks for future research.

II. OVERVIEW OF COST ESTIMATING

A. INTRODUCTION

What is cost estimation? One definition is that a cost estimate is a judgement or opinion regarding the cost of an object, commodity, or service (Batchelder and others, 1969). This judgement is arrived at through some sort of methodology based upon the assumption that experience is a reliable guide to the future. The ability to attach a cost to certain actions or factors leading to an estimate of future services is how most estimating is done presently.

The greatest challenge to cost analysts when estimating costs for military equipment is to develop relationships for new technologies usually significantly different from that of any predecessor. To predict cost of the next generation aircraft, missiles, and amphibious track vehicles with no historical basis coupled with a myriad of industrial innovations, greatly complicates the analysts' job by increasing the unknown or uncertainty of the estimate. Obviously, the analyst must weigh each of these uncertainties against any derived cost estimate. Usually if the estimate is based upon a credible statistical approach, the uncertainty can be further investigated and hopefully explained.

The approaches used in cost estimating span the entire range from intuition, at one extreme, to a detail work breakdown structure at the other. There exists five basic approaches to cost estimating: industrial engineering, catalog pricing, estimating relationships, specific analogies, and expert opinion (Batchelder and others, 1969). The driving factor on which approach to use can be a multitude of things.

For instance, if a PM has to make a quick decision about his program and is constrained by funds then he would probable opt for a parametric estimation vice an industrial engineering estimation because, it is cheaper and faster. Traditionally, most of the Defense Department cost estimations have been prepared using three of these five approaches and this will be the focus of this study. The other two, catalog pricing and expert opinion were considered too subjective for inclusion.

B. INDUSTRIAL ENGINEERING COST ESTIMATES

Estimating by industrial engineering (IE) can be defined as the bottom-up, or more casually known as the grass roots, approach to costing. Both labor and material are painstakingly measured at the lowest level of production as described by a detail work breakdown structure (WBS). After the cost have been assigned to each individual task and level, the results are aggregated to estimate the total project cost.

Industrial engineering estimates are time consuming, labor intensive, and very costly to prepare. Consequently they are

not desirable to program managers who are constantly faced with every tightening funding constraints in today's world. An example of the immense detail evolved with this type of approach is best described by the following quote, "One of the largest aerospace firms judges that the use of this approach, IE, in estimating the cost of an airframe requires about 4500 estimates to be completed before a reasonable total cost estimate is achieved." (Batchelder and others, 1969).

Industrial engineering estimates are especially vulnerable to design changes resulting from the customer and/or plant innovations that occur throughout the production process. IE estimates are based from the initial contract that does not account for any possible change in the development of a product. The production process itself can become extremely involved. Many times difficulty arises that are hard to quantify early in a process especially, when trying to assign specific cost to jobs (Large and others, 1988). Given the current world situation and inevitable fiscal cuts in the DOD budget, production requirements will slow down causing a shift upward of life cycle costs (Fox and Field, 1988). IE estimates do not anticipate such changes resulting in less accurate life cycle costs estimates.

C. SPECIFIC ANALOGIES

Throughout the IE estimating process, costs are normally based upon historical references. However, when new processes

are introduced to fabricate new hardware, analogies by expert opinion are done to makeup for the lack of reference material. For example if system X requires 100 hours to be completed, given the likenesses and differences in both design and performance requirements, then system Z is estimated to be completed in 150 hours (Batchelder and others, 1969).

The major problem with this approach is that the estimate is usually based upon a sample population of one with a subjective adjustment for task complexity or performance requirement. Considering basic statistical analysis, such a procedure can lead to misconstrued conclusions not only about the cost estimate but also, the production process itself. If the process is based solely on one person's judgement then obviously it is not reproducible. Therefore, it can not be evaluated by the recipient of the estimate. In other words, the judgement call made by the expert can not be questioned by a person outside the process. When does the analogy cost estimation work best?

Consider when a new technology changes the production process to such an extent eliminating any possible inference to historical data of past developments, the use of a specific analogy (SA) becomes the best course of action in obtaining a cost estimate. The SA estimation is best used in the early development phases of a weapon system. This estimate can be used to determine the economic feasibility of the requested design requirements. This approach when used in the

acquisition process must be considered a tool to test the affordability arena when trying to field a project.

These first two approaches provided a means to cost estimate that refer to the program manager essential insight to certain aspects of his program like initial affordability considerations. Still a more accurate and verifiable approach is needed to predict life cycle costs. This leads to the final cost estimation approach considered essential in this study of estimating relationships.

D. ESTIMATING RELATIONSHIPS

The final approach considered by this study to develop cost estimates is known as "top-down costing." With the cost of providing estimates always increasing and the fiscal dollar available to pay for these estimates seemingly decreasing, the statistical approach of top-down costing has become prominent. The statistical method well known as, " parametric cost relationships estimating ", is defined as an estimate which predicts costs by means of explanatory variables such as performance characteristics, physical characteristics, and characteristics relevant to the development process, as derived from experience on logically related systems (Baker, 1976). From this process, cost estimating relationships (CERs) are formulated using mathematical equations that relate system developmental costs to various explanatory variables and historical cost data (Miller and Sovereign, 1973).

Usually during the concept phase of the acquisition process before detailed engineering plans are formulated, parametric cost estimates with accompanying CERs are used to provided:

(1) Possible cost/performance tradeoffs in the design effort to meet stated requirement parameters.

(2) A data base for which review of cost effectiveness can be done.

(3) A method to rank competing alternatives.

This approach can compensate for unanticipated design changes and unforeseen production problems. The data used in the development of CERs was obtained from comparable weapon systems which probable experienced similar unknown circumstances and can give a historical clue to the cost associated with such changes.

Parametric cost estimates (PCE) do not replace industrial engineering estimates but, provide a means to check the validity of the cost data. Any large unexplainable differences between IE and PCE should signal the program manager that further investigation is warranted. If the application of all three approaches is done correctly, the accuracy of the final cost estimate will only improve.

1. Cost Estimating Relationships

The two major categories of CERs are input variables and output variables. First, the input CERs are a functions of the system's input parameters typically used for physical

description like weight, volume, and density. The output CERs are functions of the system's output parameters such as speed, range, and payload. If both input and output parameters are used simultaneously, in the derivation of a CER, then a possible problem with muticollinearity between variables could occur. This can lead to statistically unsound estimates and eventually to misconstruing cost estimates (Miller and Sovereign, 1973).

The generally acceptable explanatory parameters used to estimate procurement costs of a weapon system is weight. "Cost has found to correlate very well with weight.", quoted from Beltramo and Morris who, devised a method to calculate to calculate Weight Estimating Relationships (WER) from design and performance characteristics of eighteen sub-systems in aircraft (Beltramo and Morris, 1980). With this information, a CER was derived using weight as the key parameter in estimating costs. The major disadvantage with this procedure is that it involves two consecutive statistical analysis, each possibly contributing to some cumulative error. The use of one estimate to derive another estimate is statistically undesirable largely due to the possibility of error propagation from the first to the second (Gaioni and Polley, 1990). This is the major drawback of using established engineering cost data in developing a CER. To preclude this study from this problem, the focus will be on performance based data in the development of a life cycle cost CER. This

will allow the tradeoff between new required performance parameters and cost to be fully depicted.

III. COST ESTIMATION RELATIONSHIP DEVELOPMENT

A. DATA COLLECTION

The foundation on which a house is built will determine whether or not it will stand the test of time. Such is the relationship between data and derived CERs. The problem is that the analyst must pick and choose useful data from a mountain size stack of collected records and forms. The quality of the CER, like the test of time upon a house, can be no better than the data that it is built upon.

1. Cost Data

The focus of this study is the amphibious tracked vehicle. However, when developing CERs the size of the population becomes a paramount variable and in most occurrences the population must be narrowed to a specific application. This is not the case with the amphibious assault vehicle with its unique ability to land from sea to shore. Consequently, this narrowed group was broadened, taking into consideration the dual military requirement of both over-the-horizon and sustained maneuver combat ashore. The following reasons lead to this decision:

a. The only available specific type amphibious assault vehicle historical cost data would have been from the AAV7. This weapon platform has been the standard for nearly two decades and represents the only dual role vehicle capable of both land and sea operations in U.S. inventory.

b. The use of a single platform for source cost data would have limited the development of the CER to the capabilities of that vehicle. The follow on to the AAV7 will be tasked to perform two new missions types simultaneously that of OTH amphibious landings and sustain maneuver warfare with similar speeds to that of the M1A1 Abrams Tank.

Vehicle types, such as the Bradley Fighting Vehicle and the M1A1 Abrams Tank, were aggregated together base upon expected performance parameters of the new Advance Amphibious Assault Vehicle (AAAV). Extreme care was necessary to select those parameters that would minimize distortion of an estimate due, to significant physical and/or performance differences.

A final consideration to disaggregate costs into subsystems of platforms like engines, transmissions, and body type was made. This disaggregation allows the analyst to pin-point any subtle relationships that may exist between subsystems that would go unnoticed in a aggregate cost model. However, the focus of this study is to establish a relationship involving advance performance requirements and costs not of subsystem costs.

2. Performance Data

Performance data was collected from a single source, Jane's All the World's Armored Vehicles (various additions), in order to minimize possible distortion in developing an estimate that could occur when using multiple sources. The main advantage from using such a technique is that all performance data are likely have been collected in the same

manner or at least in a consistent manner over time. Units of measurement must be standardized to include environmental factors that might affect performance outcomes. For this study speed is measured in kilometers per hour (k/hr), weight in kilograms (kg), and range in kilometers (km).

B. DATA ANALYSIS/ADJUSTMENT

After all data is gathered, the analyst must ensure that it is consistent and comparable, and in most cases it is neither (Batchelder and others, 1969).

1. Cost Data

The cost data for this study was obtained from many government agencies and reports. The data was broken down into three types: Research Development Testing and Evaluation (RDT&E); Procurement (Proc.); and Operating and Support (O&S). Seven type weapon's platforms were selected as possible candidates. However when considering the wide range of required mission performance requirements, all seven candidates were considered viable. The major problem encountered with such a diverse group is that the cost data is not collected consistently throughout the Defense Department. Reasons for this phenomenon range from different type contractors to different methods when applying learning curve rates. Consequently, it was decided to limit this diversification as much as possible and use a single source,

U.S. Weapon Systems Costs 19XX (various editions) to achieve consistent cost data.

Utilizing this single source, all cost data were available except for O&S. Most importantly, the method of obtainment would be consistent and comparable over this diverse population of vehicles. The only adjustments needed for the RDT&E and Proc. cost dollars were to normalize the amounts to a consistent year. Utilizing 1985 as the base year, the statistical computer software program PACER generated the deflator table that was used throughout the analysis, that can be seen in Appendix A.

The O&S cost data was mainly obtained through the Marine Corps Combat Development Command (MCCDC), provided in a report form from the Center for Naval Analyses, CNA. The data once obtained needed to be normalized to the standard twenty year operating life cycle and inflated to constant year dollars.

2. Performance Data

As previously discussed in section A.2. of this chapter, a need for consistent and comparable performance parameters is paramount. This requirement lead to the selection of the sole source data base. Therefore the unwanted distortion that occurs with the assimilation of such information was eliminated. As mentioned in the previous section, seven candidate vehicles were chosen for the analysis

in large part due, to the mission requirements of the AAAV. Only one vehicle needed adjustment to make it comparable to the population.

Using both performance and cost data adjustments, the data base table, Table 1, was created and will be used throughout the analysis in developing a life cycle cost CER.

TABLE 1: DATA BASE TABLE

Vehicle	Crew	Range km	Speed k/hr	Weight kg	RDT&E 88	Proc 88	O&S 90
BFV	3	483	66	22443	423.7	1.23	NA
AAV7A1	3	482	54	23991	14.1	.892	1234
M1A1	4	498	72.4	57154	718.9	2.23	NA
LCAC	5	186.3	74	172720	13.4	24.4	10
M113A1	2	483	64	11156	9.1	.093	1449
LAV-25	3	603	101	10500	70.4	.724	2606
M60A3	4	480	48.3	52617	38.5	.591	NA

Note: (1) Weight is combat weight. (2) All costs are in millions of dollars. (3) Procurement costs were derived as illustrated in Appendix F. (4) LCAC O&S obtained from CNA report CRM90-253/January 1991.

The significance of Table 1 is that the CER development will come from a consolidated, consistent and valid source of information. The end result will be a CER that can accurately

depict the cost effects of changing performance parameters on LCC costs.

C. DATA MANIPULATION

All statistical manipulations were performed using the software package Parametric Cost Estimating Relationship Module (PACER) developed by DAI Inc. for use at the Defense Systems Management College (DSMC). Within the software package utilizing the applications subprogram, Cost Estimating Relationships (CERs) can be developed from resources and physical or technical parameters of a particular weapon system. This subsystem enables the user to perform regression analysis on input data in any of seven standard forms (linear, power, exponential, semi-log a/b, quadratic or log-linear). The user also, has the option of allowing the computer to select the best fit regression equation (Pacer Manual, 1990). In this study, all regression analyses were computer generated utilizing the best fit regression technique.

1. Statistical Tools

After performing the regression analysis, PACER provided many statistical outputs to allow the analyst to test the validity of the regression equation to the various inputs. The following is a brief description of the statistical outputs that were verified.

a. Accuracy of Equation

To determine the accuracy with which the estimating equation describes the sample observations, the analyst must use the statistical measure of coefficient of determination (R^2), coefficient of variation (CV), and standard error (SE) (Batchelder and others, 1969).

(1) Coefficient of Determination

Known as R^2, the coefficient of determination measures the association between two or more variables by relating the degree of variation in the dependent variable , cost , to the variations of the independent variables, performance . For this study an R^2 value of 80% is considered acceptable (Miller and Sovereign, 1973).

(2) Coefficient of Variation

Known as CV, measures the association between standard error to the mean of the sample dependent variable. For this study a value of less than 20% is considered acceptable (Batchelder and others, 1969).

(3) Standard Error

Known by SE, is defined as the square root of the unexplained variance of the dependent variable. The smallest SE was the goal for this study because, the smaller the better the estimating equation (Batchelder and others, 1969).

b. Validity of Equation

To establish the validity of a multi-variable regression equation, the statistical measures of t-ratio and F-statistic provide the analyst a method to ensure that the derived equation will provide the most accurate results.

(1) t-ratio

Used in multiple regression analysis to indicate the significance or nonsignificance between explanatory variables that leads to determination of whether there exist an unacceptable strong relationship between those variables (Batchelder and others, 1969). For this study, a t-ratio greater than two was acceptable (Miller and Sovereign, 1973).

(2) F-statistic

Used in regression analysis to determine whether an incremental improvement associated with the addition of a variable is significant (Batchelder and others, 1969). For this study, a F-statistic greater than four was considered acceptable.

2. Statistical Data Table

To summarize the statistical requirements used to determine whether a CER was acceptable or not is illustrated in the following table:

TABLE 2: STATISTICAL PARAMETERS

Parameter	Value
R^2	>.8
CV	<.2
SE	<.2
t-ratio	>2
F-statistic	>4

The consolidation into Table 2, statistical qualifiers to test the validity of CERs is consistent with similar studies of parametric cost estimating. One example of such a study was conducted upon Marine Corps Medium Lift Helicopters where CERs were evaluated in a similar manner as in this study (Gaioni and Polley, 1990). Utilizing information from Table 1 with Table 2 qualifiers, the trade-off on increasing range and speed in life cycle cost terms of the new AAAV will be apparent.

D. CER DERIVATION

1. RDT&E Cost Model

Utilizing the data available from Table 1, the variables RDT&E costs, and the performance parameters of range, speed, and weight for the total population, multiple regressions were perform that are illustrated in Appendix 2

using statistical parameters as established by Table 2 resulting in the following model:

MODEL I

$$\text{RDT\&E Costs} = -3096.729 + 2.414\ \text{Range} + 35.944\ \text{Speed}$$

As illustrated, the best fit equation determined by PACER was a linear regression equation. This equation was based upon four vehicle types as illustrated in the following table:

TABLE 3: RDT&E DATA

Vehicle	Range	Speed	RDT&E
AAV7A1	482	54	14.1
BFV	483	66	423.7
M1A1	498	72	718.9
LCAC	186	74	13.4

The vehicles were chosen to fulfill the dual role requirement that the AAAV be capable of both OTH and sustained land warfare.

The statistical parameters of this model are as follows in Table 4:

TABLE 4: RDT&E STATS

Parameter	Acceptable	Achieved
R^2	>.8	.99
CV	<.2	.075
SE	<.2	.219
t-ratio	>2	24.7(R)/22.2(S)
F-statistic	>4	367.4

2. Procurement Cost Model

Utilizing Table 1, analyzing all seven type vehicles, a multiple regression analysis was performed as illustrated in Appendix 3. With consideration to the constraints as listed in Table 2, the following cost model was developed:

MODEL II

Procurement Costs = -27.199 + .055 Range + .026 Speed

PACER selected the linear form of regression equation as best fit. This equation was based upon a final population of four vehicle types that are displayed in the following table:

TABLE 5: Proc Data

Vehicle	Range	Speed	Proc
BFV	483	66	1.23
AAV7A1	482	54	.892
M1A1	498	72	2.23
M60A3	480	48	.591

The population selection represents consideration for the mission duality for the new AAAV.

The statistical measurements achieved from this regression are as follows in Table 6:

TABLE 6: Proc Stat

Parameter	Acceptable	Achieved
R^2	>.8	.999
CV	<.2	.025
SE	<.2	.031
t-ratio	>2	14.6(R)/9.1(S)
F-statistic	>4	813.4

3. Operating and Support Cost Model

Using O&S cost data and the performance parameters of range, speed, and weight on four vehicles as illustrated in Table 1, multiple regression analysis that can be seen in Appendix 4 was conducted utilizing requirements as set forth in Table 2 in the development of the following model:

MODEL III

$$\text{O\&S Costs} = -2097.358 + 5.248\ \text{Range} + 15.297\ \text{Speed}$$

This linear expression was selected as the best fit regression equation as determined by PACER for the given inputs. The equation was based upon a population of four vehicles as illustrated in the following table:

TABLE 7: O&S Data

Vehicle	Range	Speed	O&S
AAV7A1	482	54	1234
M113A1	483	64	1449
LAV-25	603	101	2602.3
LCAC	186.3	74	10

The population selection included consideration that only one vehicle had reach its 20 year life cycle.

The statistical results achieved from this regression analysis are displayed in the following table:

TABLE 8: O&S Stat

Parameter	Acceptable	Achieved
R^2	>.8	1
CV	<.2	.03
SE	<.2	41.1
t-ratio	>2	37.6(R)/12.5(S)
F-statistic	>4	5.73

4. Cost Model Summary

As illustrated by Tables 3,4,5,6,7, and 8, the CER Cost Models I,II, and III are statistical sound. The purpose

of this study is to develop a model for predicting life cycle cost as mandated by required performance parameters. The result was the development of three separate cost elements that when summed together provide just that. Furthermore, according to the statistical results achieved by the costs models, an accurate LCC estimate can be achieved.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. COMPARISON OF COST PREDICTIONS

The three models formulated for life cycle cost prediction are summarized as follows:

MODEL I

RDT&E Costs = -3096.729 + 2.414 Range + 35.944 Speed

MODEL II

Procurement Costs = -27.199 + .55 Range + .026 Speed

MODEL III

O&S Costs = -2097.358 + 5.248 Range + 15.297 Speed

The objective of this study was to relate performance parameters to three areas of cost to arrive at an accurate prediction of life cycle cost. Given these derived models, the analysts must determine whether or not the outcomes associated with the predictions make sense. For this study, predicted life cycle costs were obtained from the AAAV program office as illustrated in the report, Preliminary Life Cycle Cost Estimate (LCCE), 11 May 1988. The LCCE costs were prepared in response to Milestone 0 requirements as required

by the acquisition process. This report was considered valid for this study and will be the basis for a comparative analysis of this study's cost predictions.

1. RDT&E Costs

From the LCCE, the RDT&E Costs were based upon 1375 basic vehicles as illustrated below:

$$\text{RDT\&E Costs (FY88)} = \$709{,}436{,}000$$

Using Model I and the desired performance requirements that are required to meet mission objectives as stated in Chapter I and referred to in an article in the Marine Corps Gazette, September 1991 issue, titled "AAAV Program Nears Milestone", the following RDT&E Costs are derived:

$$\text{RDT\&E Costs (FY88)} = -3096.729 + 2.414(498) + 35.944(72.4)$$

$$\text{RDT\&E Costs} = \$707{,}790{,}000$$

The difference between the derived RDT&E Costs and those provided in the preliminary LCCE are as follows:

$$\text{RDT\&E Costs Difference} = \$1{,}646{,}000$$

This equates to less than 1% difference between predictions. Therefore, the derived RDT&E Cost Model seemingly predicts costs as accurate as the LCCE Cost Model.

2. Procurement Costs

Using the LCCE, the procurement costs were based upon 1375 basic vehicles as displayed below:

$$\text{Procurement Costs (FY88)} = \$3,603,139,000$$

Using Model II and the desired performance parameters, the following procurement costs are derived:

$$\text{Procurement Costs} = -27.199 + .055(498) + .026(72.4)$$

$$\text{Procurement Costs} = \$2.0734 \text{ per unit}$$

$$\text{Total Procurement Costs} = (1375 \text{ units})\$2.0734 \text{ per unit}$$

$$\text{Total Procurement Costs} = \$2,850,925,000$$

The difference between the derived procurement costs and the LCCE costs is as follows:

$$\text{Procurement Costs Difference} = \$752,214,000$$

This equates to a 20.9% difference between predictions. In the opinion of this author, this significant difference can be attributed to the methodology used by each study. The LCCE

was based upon the more traditional method of obtaining theoretical first unit cost, unlike this study that used only historical data and require performance parameters.

3. Operating and Support Costs

The predicted O&S Costs for the required 1375 basic vehicles as presented in the LCCE are as follows:

$$\text{O\&S Costs (FY88)} = \$2{,}276{,}862{,}200$$

Utilizing Model III and the required performance parameters, the following O&S Costs were derived:

$$\text{O\&S Costs} = -2097.358 + 5.248(498) + 15.297(72.4)$$

$$\text{O\&S Costs (FY90)} = \$1623.65$$

To deflate the predicted cost to FY88 dollars, Appendix A was used and the results of that computation are as follows:

$$\text{O\&S Costs (FY85)} = \$1623.65/1.174 = \$1383$$

$$\text{O\&S Costs (FY88)} = \$1383(1.098) = \$1518.534$$

$$\text{O\&S Costs (FY88)} = \$1{,}518{,}534{,}000$$

The difference between the cost predictions are as follows:

$$\text{O\&S Costs Difference} = \$758{,}328{,}200$$

This equates to a 33.3% difference between predictions. Like procurement cost, this significant difference can be attributed to the attainment of cost data. The methodology used by this study used only required performance parameters and historical cost data from similar technologies. On the other hand, the LCCE broke cost down into a more traditional fashion which in this author's opinion can account for the diverse differences.

4. Life Cycle Costs

After aggregating all three cost predictions together for both the LCCE report and this study, the following life cycle cost are achieved:

LCC (LCCE) = $6,589,437,200 (FY88)

LCC (Study) = $5,077,249,000 (FY88)

The major difference between the two predictions specifically fell into the application of methodology. This study was solely based upon the development of cost estimating relationships using parametric costing techniques. The preliminary LCCE used the traditional method in its cost development. The most significant differences came from procurement costs and O&S costs. The procurement costs developed by the LCCE used input parameters such as weight, engine type, and transmission type in developing theoretical

first unit cost leading to a final total procurement cost CER. The operating and support costs developed in the LCCE report broke down the twenty year costs into specific areas such as personnel required, depot maintenance, and spares. This method is both cost intensive and labor intensive to develop. For any cost estimation, the analyst must be able to provide adequate documentation to enable the requester, in this case the program manager, to verify the validity of the projection. Even with two significantly different predictions as illustrated here, the program manager can decide which of the approaches best fit his needs at the time. Early in the development of a program a quick and reasonable estimate like the one provide by this study can aid in his decision process on issues of affordability.

B. PARAMETRIC RISK ANALYSIS

There are trends in the development of parametric cost estimating to link it with statistical risk analysis. The statistical approach used by the analyst can be used to quantify the uncertainty with developed cost estimations (Stewart and Wyskida, 1987). The statistical information that is used to derive a CER can be used to establish confidence bounds about the regression line. These confidence limits take into account both standard deviation associated with unexplained variances in the CER data base and the distance from the mean of the independent variable (Stewart and

Wyskida, 1987). This leads to conclusions about the derived CER uncertainty to whether or not the estimate would not exceed this value with a derived confidence level. The most commonly used test to determine whether an incremental improvement with the addition of a variable is the F-statistic (Batchelder, C. and others). Theoretically most experienced managers would like to try to achieve a confidence level of 95% on cost estimations (Stewart and Wyskida, 1987).

In this study, three separate CER cost models were developed. Associated with that development, confidence bounds were established that require further investigation.

1. RDT&E CER

Utilizing the software package, PACER, the following best fit regression equation was determined:

$$\text{RDT\&E Costs} = -3096.729 + 2.414\ \text{Range} + 35.944\ \text{Speed}$$

The established confidence limits on the coefficients derived from this CER were 95% for range and 95% for speed. Based on this information and the F-statistic being 95%, the results are well within the desired range of 95% as previously stated.

2. Procurement CER

Again utilizing PACER, the following best fit regression equation was determined:

$$\text{Procurement Costs} = -27.199 + .055\ \text{Range} + .026\ \text{Speed}$$

The associated confidence levels on the coefficients were 95% for range and 90% for speed. Based on this information and the F-statistic being 95%, it would seemingly lead to the conclusion that the results are well within the desired range of 95 % as previously stated.

3. Operating and Support CER

Utilizing the PACER statistical software package, the following best fit regression equation was arrived at:

$$\text{O\&S Costs} = -2097.358 + 5.248 \text{ Range} + 15.297 \text{ Speed}$$

The associated confidence levels on the coefficients for both range and speed were like procurement cost CER 95% and 90%, respectfully. As stated in the previous section, this information in conjunction with the F-statistic being 95%, the results are well within the desired limitation of 95%.

4. Summary

Taken all the established confidence limits into account, the program manager might be tempted to accept these derived CERs as a fairly accurate predictor of cost, but a more explicit definition of uncertainty must be addressed. The levels of confidence are linked to the data plot of CERs as reflected by the standard error. In other words, the confidence limits reflect only those risk factors that caused the dispersion in the original data. Therefore, if the data

changes before the confidence levels are established then the confidence statement might be misconstruing. This is due to the fact that the data is based upon historical data which are basically stagnant unlike continuously changing data of a process line. The program manager in concert with the cost analyst must weigh this fact when considering the validity of CER cost predictors (Stewart and Wyskida, 1987).

Other cost risk analysis techniques involving Monte Carlo simulation, network analysis and a host of other risk assessment techniques, allow the analyst to deal with uncertainties like those associated with input data and their effects upon cost are beyond the scope of this study.

C. OTHER STATISTICAL CONSIDERATIONS

1. Residual Analysis

The validity of any derived regression equation can be verified by analyzing residuals. Residuals are developed when taken the data used to develop a CER and reapplying it through the derived CER resulting in estimates, in this case costs, that can be compared to the original value. In effect, the deviations from this technique will illuminate any apparent problem with stratification of data (Batchelder and others, 1969). In laymen terms, the stratification of a data means the grouping of data points that can indicate the existence of a subtle relationship associated with the independent

variables. These relationships may need further investigating because they can misconstrue the regression analysis.

a. RDT&E Costs

The software package, PACER, derived Model I to describe the behavior of the provided RDT&E cost data as follows:

RDT&E Costs = -3096.729 + 2.414 Range + 35.944 Speed

After applying the original data used in the development of this CER the following table, TABLE 9, resulted:

TABLE 9 : RDT&E RESIDUALS

Vehicle	Act Cost ($M)	Est Cost ($M)	Deviation (Act-Est)	% Dev
AAV7A1	14.1	7.8	6.3	44.7
BFV	423.7	441.5	-17.8	-4.2
M1A1	718.9	707.8	11.1	1.5
LCAC	13.4	12.8	.6	4.5

Average of the absolute value of percent deviation = 13.7%

The data plot of actual cost versus estimated cost can be seen in Appendix E. After analyzing the derived data and the data

plot, the derived CER was considered valid since no major stratification seem to exist.

b. Procurement Costs

The best fit regression equation as derived by PACER statistical software to describe the behavior of procurement costs are illustrated by Model II:

$$\text{Procurement Costs} = -27.199 + .055\ \text{Range} + .026\ \text{Speed}$$

Utilizing the original data with application back through this derived CER Model, the following table resulted:

TABLE 10 : PROCUREMENT RESIDUALS

Vehicle	Act Cost ($M)	Est Cost ($M)	Deviation (Act-Est)	% Dev
BFV	1.23	1.08	.15	12.5
AAV7A1	.892	.715	.177	19.8
M1A1	2.23	2.06	.17	7.6
M60A3	.591	.457	.134	22.7

Average of the absolute value of percent deviation = 15.7%

The data plot of actual cost versus estimated cost can be seen in Appendix E. After careful consideration for both the data

plot and Table 10 results, the derived CER was considered valid with no stratification of data being noted.

c. Operating and Support Costs

Utilizing the software package PACER, Model III was developed to describe the behavior of O&S cost data:

$$\text{O\&S Costs} = -2097.358 + 5.248 \text{ Range} + 15.97 \text{ Speed}$$

Utilizing the original data with re-application to the derived CER model, the following table resulted in the description of O&S residuals:

TABLE 11 : O&S RESIDUALS

Vehicle	Act Cost ($M)	Est Cost ($M)	Deviation (Act-Est)	% Dev
AAV7A1	1234	1258.2	-24.2	-2.0
M113A1	1449	1416.4	32.6	2.2
LAV-25	2606	2612.2	-6.2	-.24
LCAC	10	12.3	-2.3	-23

Average of the absolute value of percent deviation = 6.9%

The data scatter plot of actual versus estimated cost can be seen in Appendix E. Utilizing the data plot analysis and the

results from Table 11, the derived O&S Cost CER was considered valid due to the absence of any notable stratification of data.

d. *Residual Analysis Conclusion*

Considering the available data plots in Appendix E and Tables 9, 10, and 11, the derived cost estimating relationship were all considered valid when considering the stratification of data as means to test the statistical significance. However, another statistical parameter that is readily available to help demonstrate the validity of explanatory variables used in the deviation of CERs is the correlation coefficient.

2. Correlation Coefficient Analysis

There exists numerous statistical tools that can aid in the evaluation of parametric cost models such as coefficient of determination (R^2) and standard error (SE), and the correlation coefficients all of which need to be evaluated (Miller and Sovereign, 1973). A model must contain correlation coefficients that are statistically significantly different from zero. Any variables that are not should be dropped from consideration in the evaluation. In this analysis, the final derived Cost Model CERs I, II, and III generated the following correlation coefficient matrices:

TABLE 12 : RDT&E CORRELATION COEFFICIENT MATRIX

	RDT&E	Range	Speed
RDT&E	1.000	.575	.410
Range	.575	1.000	-.510
Speed	.410	-.510	1.000

TABLE 13 : PROCUREMENT CORRELATION COEFFICIENT MATRIX

	Procurement	Range	Speed
Procurement	1.000	.974	.932
Range	.974	1.000	.826
Speed	.932	.826	1.000

TABLE 14 : O&S CORRELATION COEFFICIENT MATRIX

	O&S	Range	Speed
O&S	1.000	.960	.545
Range	.960	1.000	.290
Speed	.545	.290	1.000

From this information, the conclusion reached by this analysis is that all final CER Cost Models seemingly have the necessary correlation coefficients in all explanatory variable cases.

D. FINAL CONSIDERATIONS

This study's aim was to develop a method to predict life cycle cost using only performance parameters and similar historical cost data. The statistical requirements were met consistently to all available standard comparisons. Therefore, the study reinforced the fact that parametric cost estimating techniques provide a viable alternative to more expensive cost estimate developments. When considering today's world of the never-ending shrinking Defense Budget, the utilization of this technique will only grow. The biggest drawback for the program manager when using this technique is that it is limited to the accuracy of the data base. If the data base can be verified cheaply and the information is readily available then the use of parametric cost analysis will know unlimited bounds.

1. Future Research

The use of performance parameters to develop a cost estimating relationship is data dependent. Only long term data refinement will aid in generating accurate cost data. The future of this field is just starting to open and the application of these techniques will only add to the development of performance base cost estimating.

The use of PACER statistical software developed for DSMC for their acquisition management training is in its infancy stage. Further refinement in its use will help standardize the cost development procedures throughout the Defense Department.

As the AAAV proceeds through its development down that milestone acquisition line, the validity of this derived CER for life cycle cost can be tested. The more developed the system becomes the more refined the cost model should become and the more useful to new cost analysts of the future.

APPENDIX A-INFLATION/DEFLATION TABLE

1985	1.0000
1986	1.0290
1987	1.0609
1988	1.0980
1989	1.1365
1990	1.1740
1991	1.2080
1992	1.2370
1993	1.2667
1994	1.2971
1995	1.3282
1996	1.3601
1997	1.3927
1998	1.4262
1999	1.4604

TABLE GENERATED BY PACER STATISTICAL SOFTWARE PROGRAM

APPENDIX B-RDT&E CER DERIVATION

A. 1ST ITERATION

NUMBER OF OBSERVATIONS:7 (BFV,AAV7A1,M1A1,LCAC,M113A1,LAV,M60)

NUMBER OF VARIABLES:4 (RANGE,SPEED,WEIGHT,COSTS)

RDT&E COSTS= $5.142e^{-30}$ $RANGE^{5.855}$ $SPEED^{3.563}$ $WEIGHT^{2.013}$pg.49

R^2=.627 SE=256.53 F-statistic=1.678

t-ratio=2.2R/1.3S/1.9W

RDT&E COSTS= -66.631+.012WEIGHT-6.8$e^{-08}$$WEIGHT^2$pg.51

R^2=.328 SE=279.9 F-statistic=.974 t-ratio=1.3

RDT&E COSTS=9.9$e^{-7}$$RANGE^{1.7}$$SPEED^{1.8}$pg.50

R^2=.2 SE=374.2 F-statistic=.5 t-ratio=.8R/.6S

RDT&E COSTS=-2256.5+66.9SPEED-.43$SPEED^2$pg.54

R^2=.25 SE=296 F-statistic=.66 t-ratio=1.15

RDT&E COSTS=.002$RANGE^{1.67}$pg.53

R^2=.14 SE=334.5 F-statistic=.79 t-ratio=.89

RDT&E COSTS=-66.631+.012WEIGHT-6.8$e^{-8}$$WEIGHT^2$pg.56

R^2=.32 SE=279.9 F-statistic=.974 t-ratio=1.3

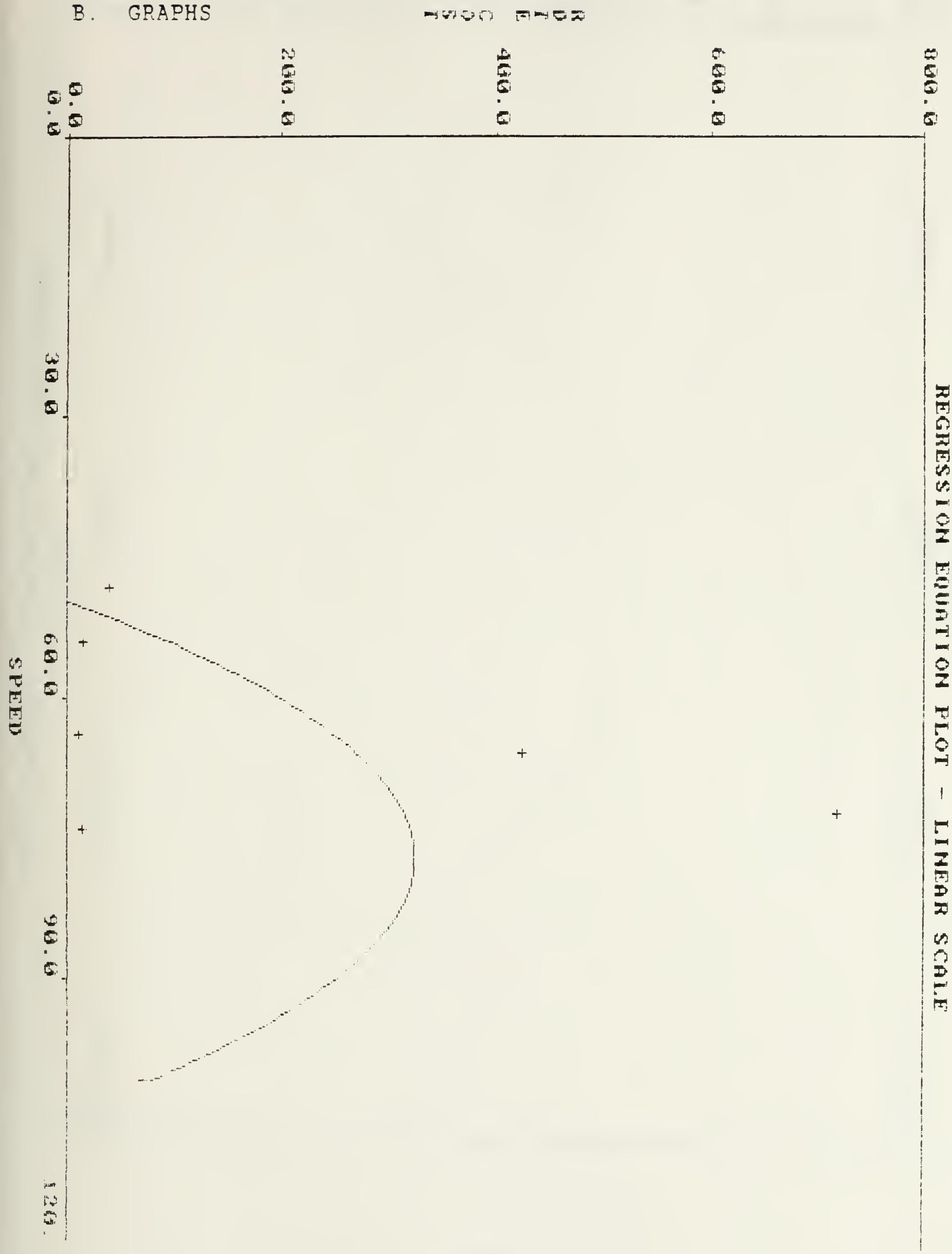
RANGE=1514.8-30.9SPEED+.215$SPEED^2$pg.55

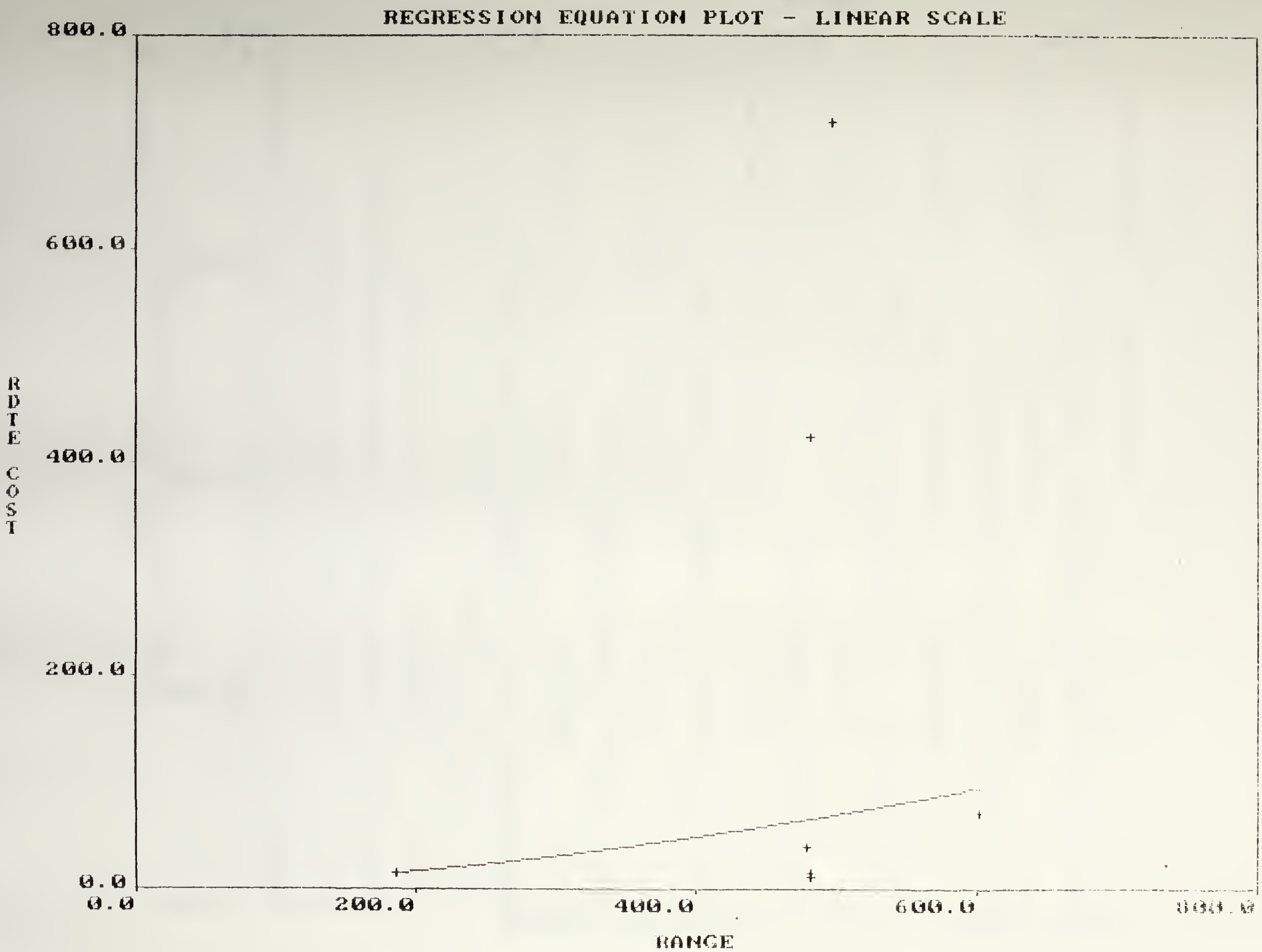
R^2=.31 SE=130.7 F-statistic=.9 t-ratio=-1.19

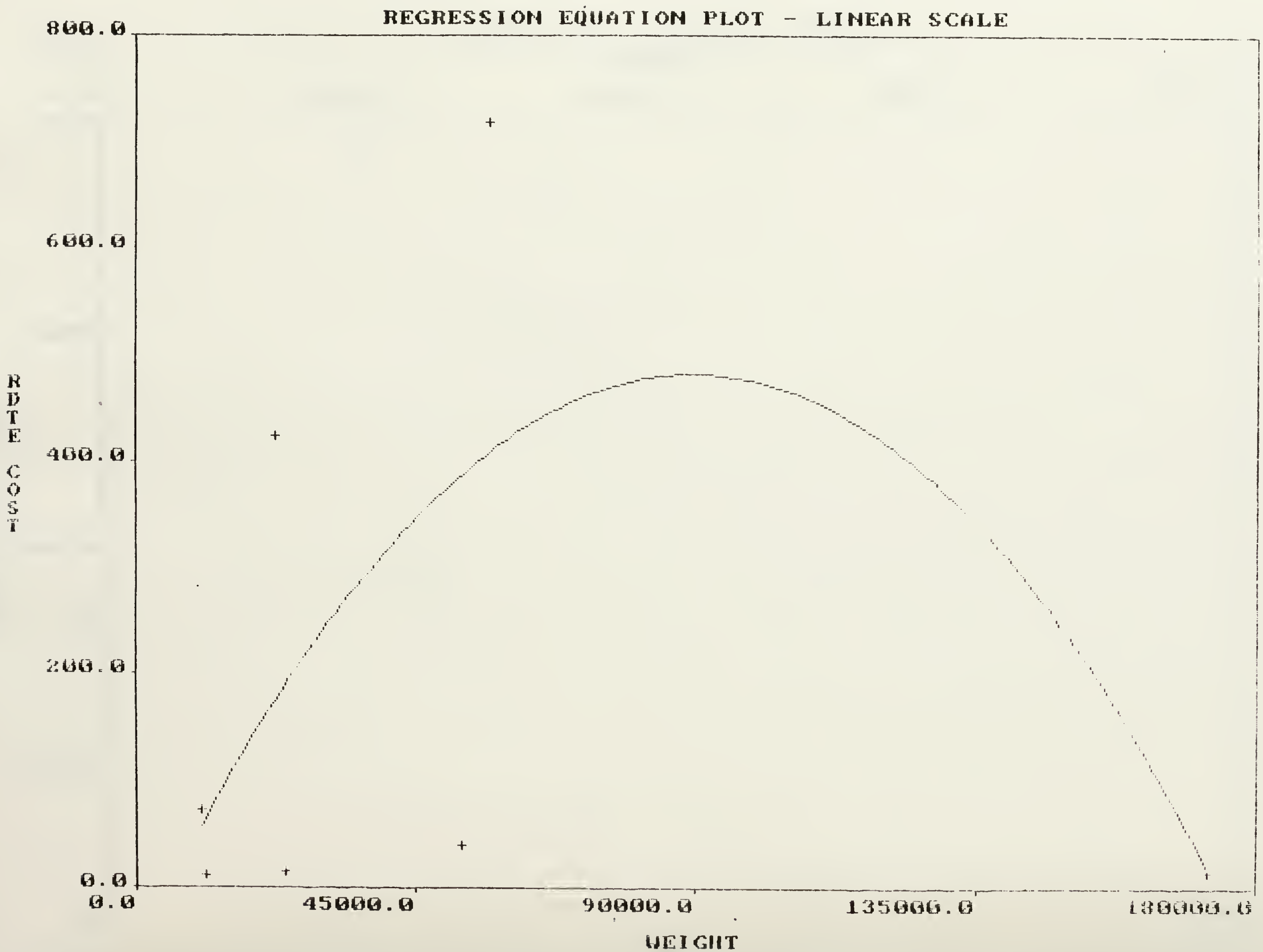
WEIGHT=207346.875-429.6RANGE+584.5SPEED pg.52

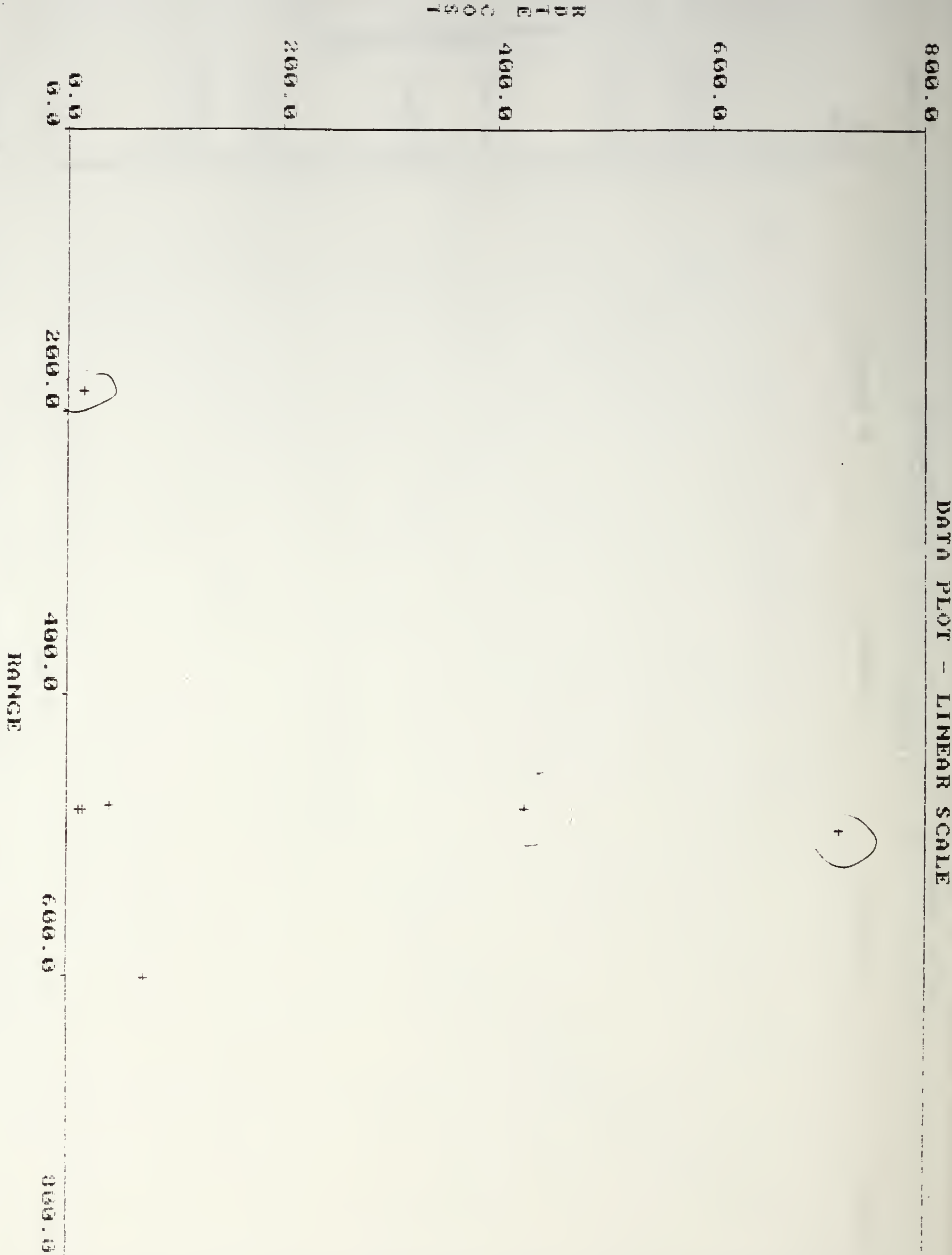
R^2.897 SE=2.24 F-statistic=17.5 t-ratio=-5.9

B. GRAPHS

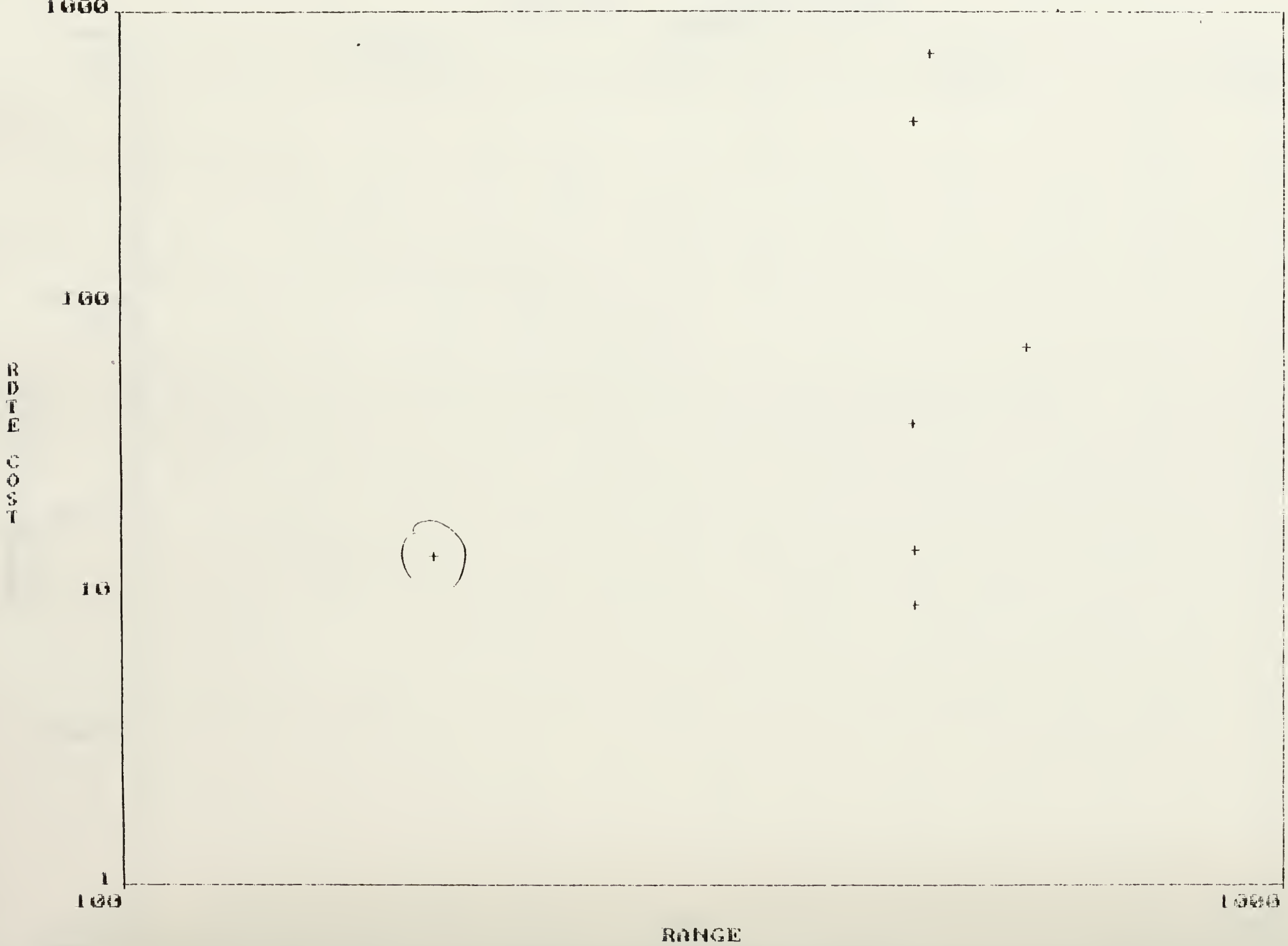

REGRESSION EQUATION PLOT - LINEAR SCALE
0.0
200.0
400.0
600.0
800.0
0.0
30.0
60.0
90.0
120.
SPEED

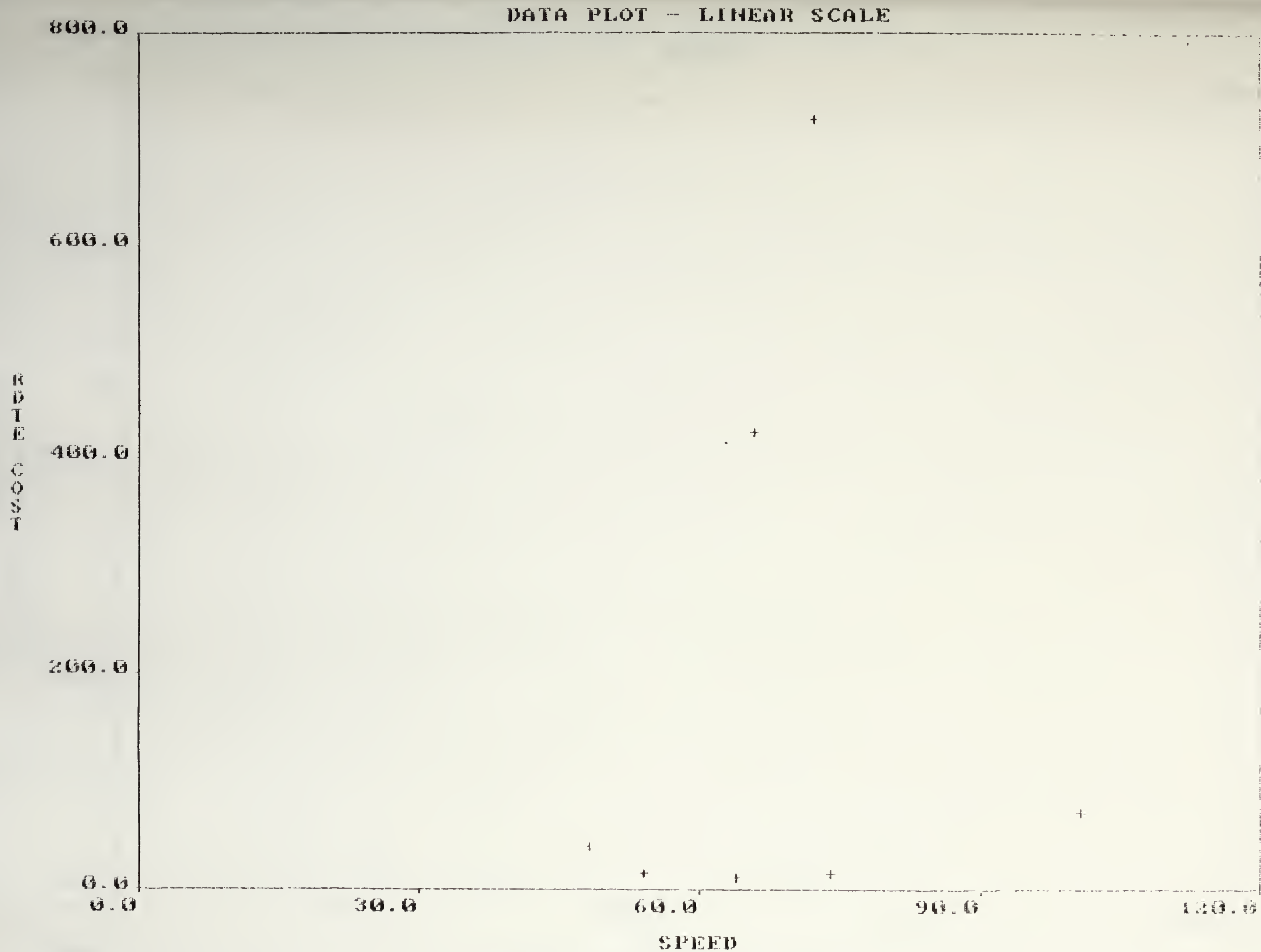

REGRESSION EQUATION PLOT - LINEAR SCALE
800.0
600.0
400.0
200.0
0.0
RDTE COST
0.0
200.0
400.0
600.0
800.0
RANGE

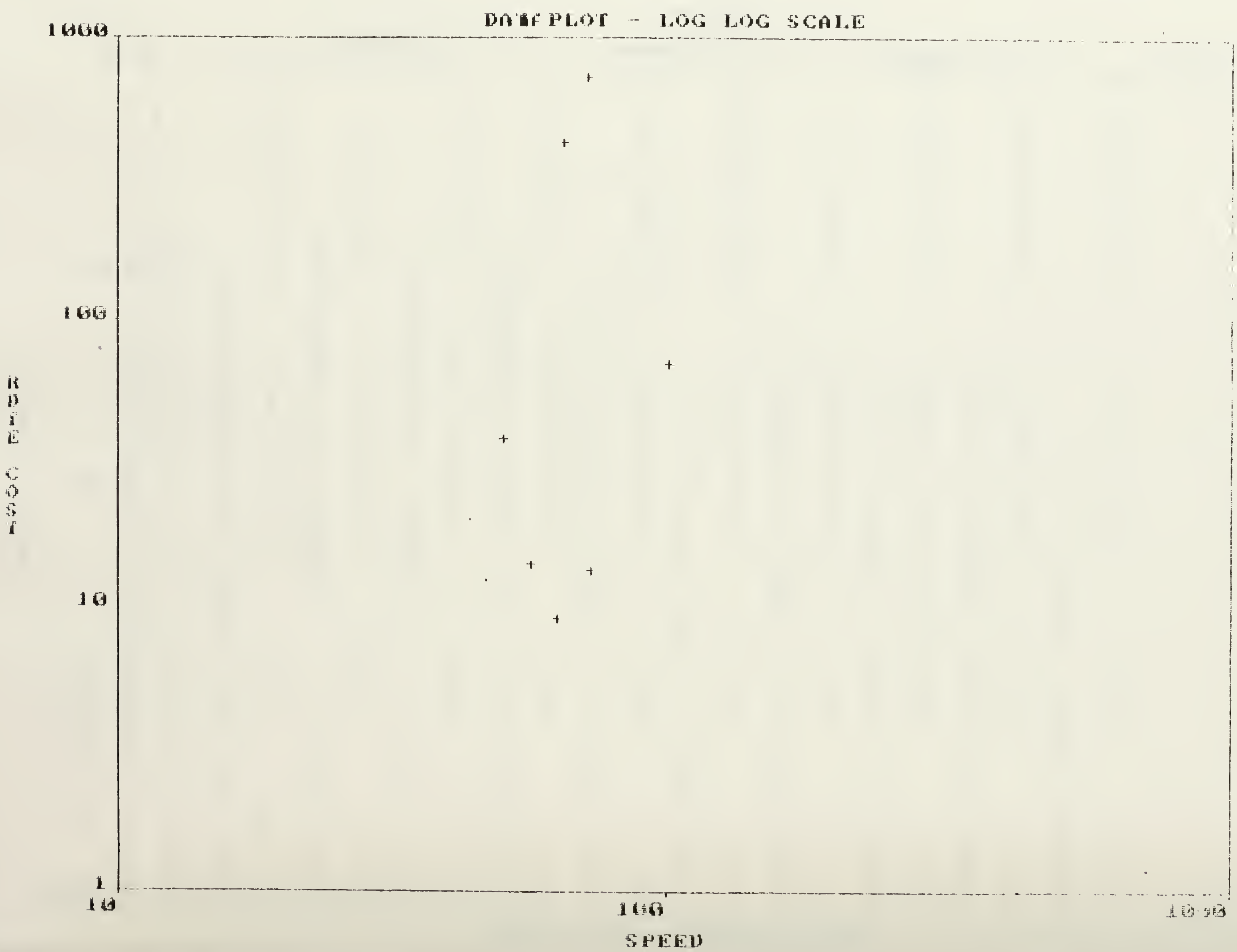

REGRESSION EQUATION PLOT - LINEAR SCALE
800.0
600.0
400.0
200.0
0.0
RDTE COST
0.0
45000.0
90000.0
135000.0
180000.0
WEIGHT

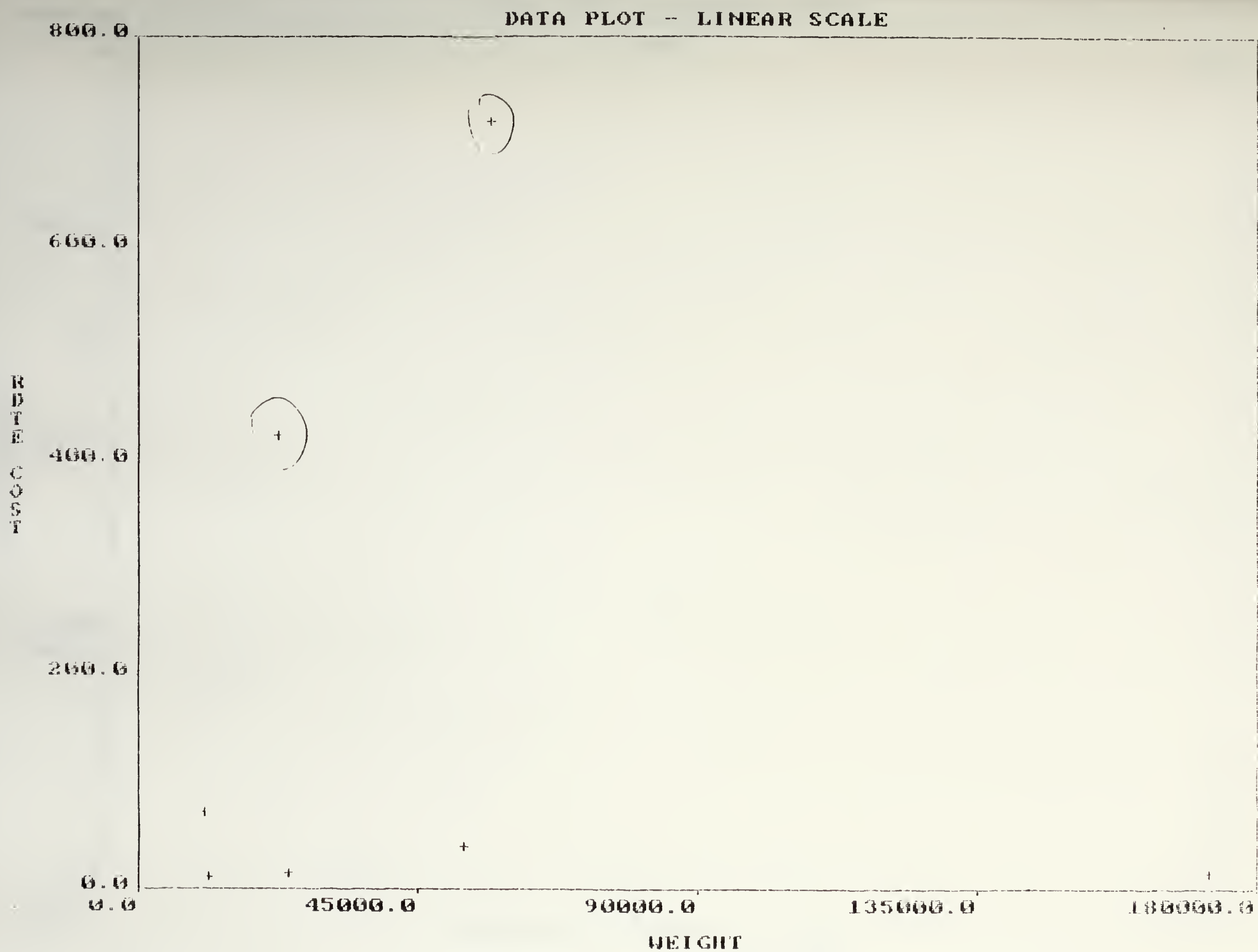

DATA PLOT - LINEAR SCALE
RANGE
0.0
200.0
400.0
600.0
800.0

DATA PLOT - LOG LOG SCALE




DATA PLOT - LINEAR SCALE
800.0
600.0
400.0
200.0
0.0
RATE COST
0.0
30.0
60.0
90.0
120.0
SPEED


DATF PLOT - LOG LOG SCALE
1000
100
10
1
10
100
1000
SPEED
RATE COST


DATA PLOT -- LINEAR SCALE
800.0
600.0
400.0
200.0
0.0
RDTE COST
0.0
45000.0
90000.0
135000.0
180000.0
WEIGHT

C. 2ND ITERATION

NUMBER OF OBSERVATIONS:4 (AAV7A1,M113A1,LAV,M60)

NUMBER OF VARIABLES:4 (RANGE,SPEED,WEIGHT,COSTS)

RDT&E COSTS=$-45.23\ \mathrm{RANGE}^{-.23}+23.5\ \mathrm{WEIGHT}^{-5.3}$pg.63

R^2=.945 SE=81.9 F-statistic=8.5 t-ratio=3.5R/-2.7S

RDT&E COSTS=$83.7 - .005\mathrm{WEIGHT}+7.5e^{-8}\ \mathrm{WEIGHT}^2$pg.58

R^2=.25 SE=41.9 F-statistic=.17 t-ratio=-.58

RDT&E COSTS=$332.6 -9.4\ \mathrm{SPEED}+ .068\ \mathrm{SPEED}^2$pg.59

R^2=.97 SE=8 F-statistic=17.9 t-ratio=-3.5

RDT&E COSTS=$25013.8 -93.7\ \mathrm{RANGE}+.087\ \mathrm{RANGE}^2$pg.67

R^2=.99 SE=3.7 F-statistic=85.1 t-ratio=-6.12

RDT&E COSTS=$7.2\ e^{-16}\ \mathrm{SPEED}^{4.8}\ \mathrm{WEIGHT}^{1.8}$pg.65-66

R^2=.99 SE=2 F-statistic=125 t-ratio=15.7S/13.7W

RDT&E COSTS=$e^{(-6.5+.017\mathrm{RANGE}+.00004\mathrm{WEIGHT})}$pg.61-62

R^2=1 SE=.092 F-statistic=3.75 t-ratio=268R/181W

RDT&E COSTS=$651-6.3\ \mathrm{SPEED}+.058\ \mathrm{SPEED}^2$pg.66

R^2=.99 SE=3.3 F-statistic=477.7 t-ratio=-5.6

WEIGHT=$1.5e^{-17}\ \mathrm{RANGE}^{1.5}\ \mathrm{SPEED}^{-5.6}$pg.62-63

R^2=.98 SE=5.06e+3 F-statistic=35.7 t-ratio=4.9R/-7S

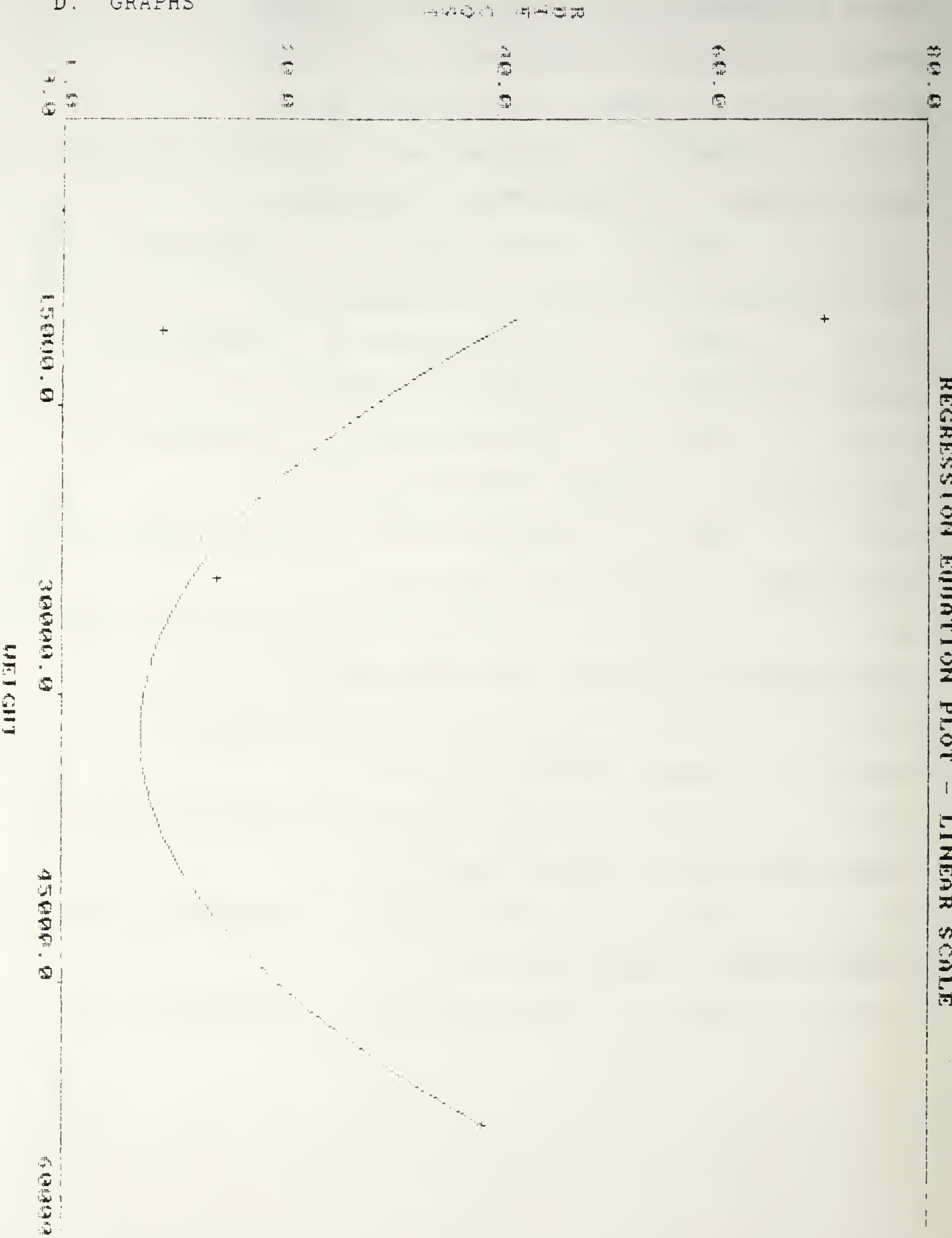
SPEED=$.00095\ \mathrm{RANGE}^{.06}\ \mathrm{WEIGHT}^{-.017}$pg.61-62

R^2=.99 SE=1.49 F-statistic=217 t-ratio=12.2R/-7W

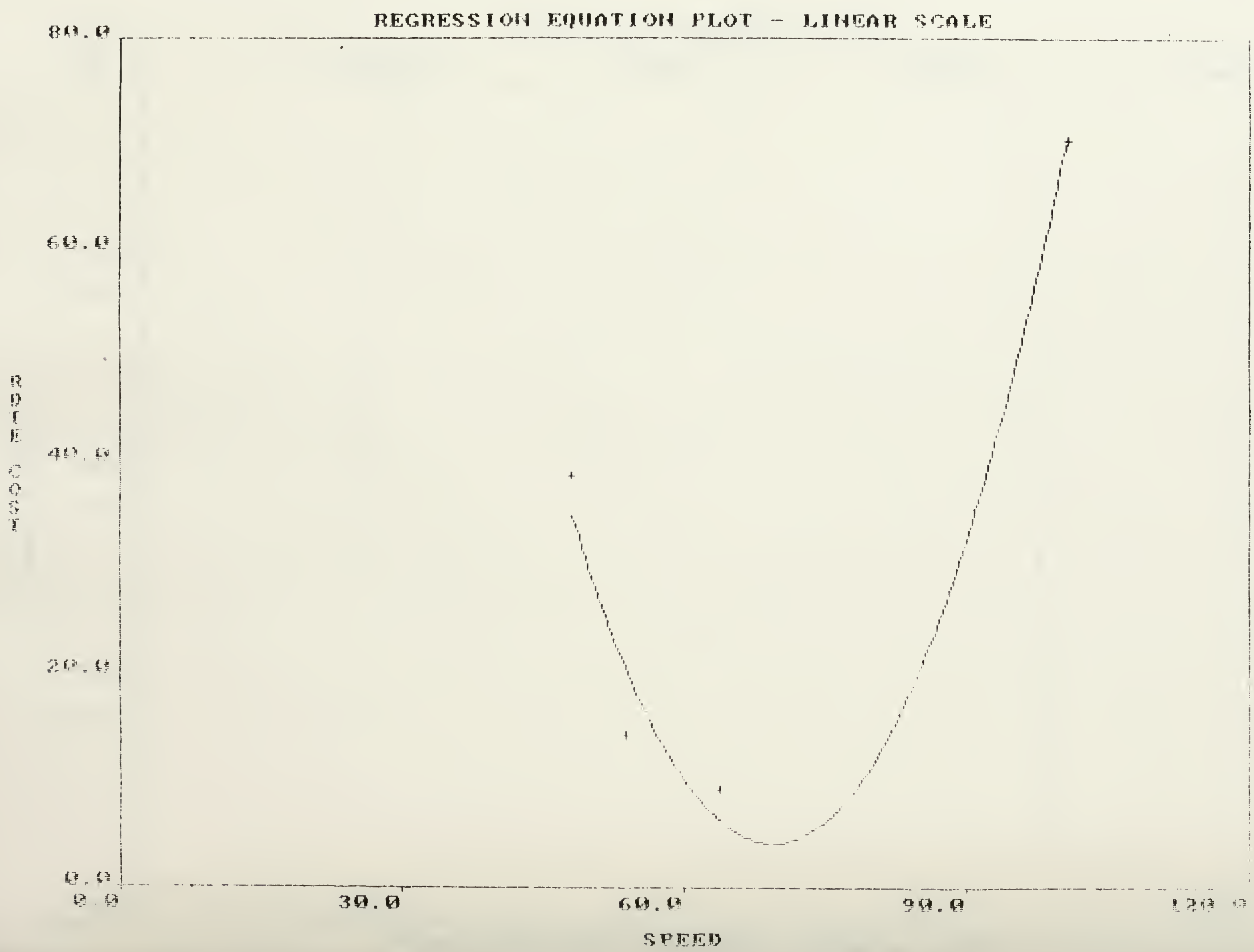
RANGE=$30\ \mathrm{SPEED}^{.48}\ \mathrm{WEIGHT}^{.08}$pg.63-64

R^2=.99 SE=6.2 F-statistic=110 t-ratio=12S/4.9W

D. GRAPHS

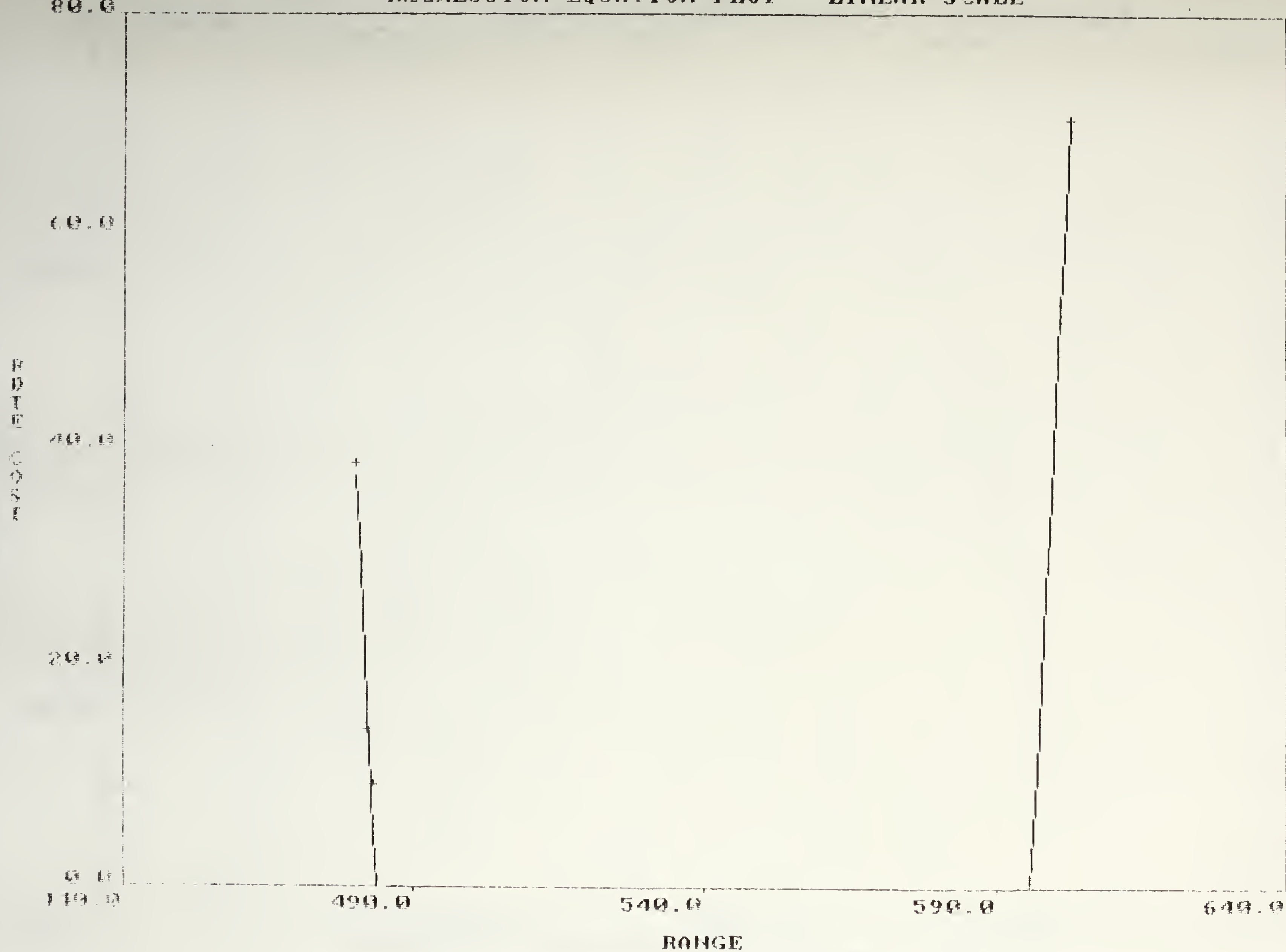


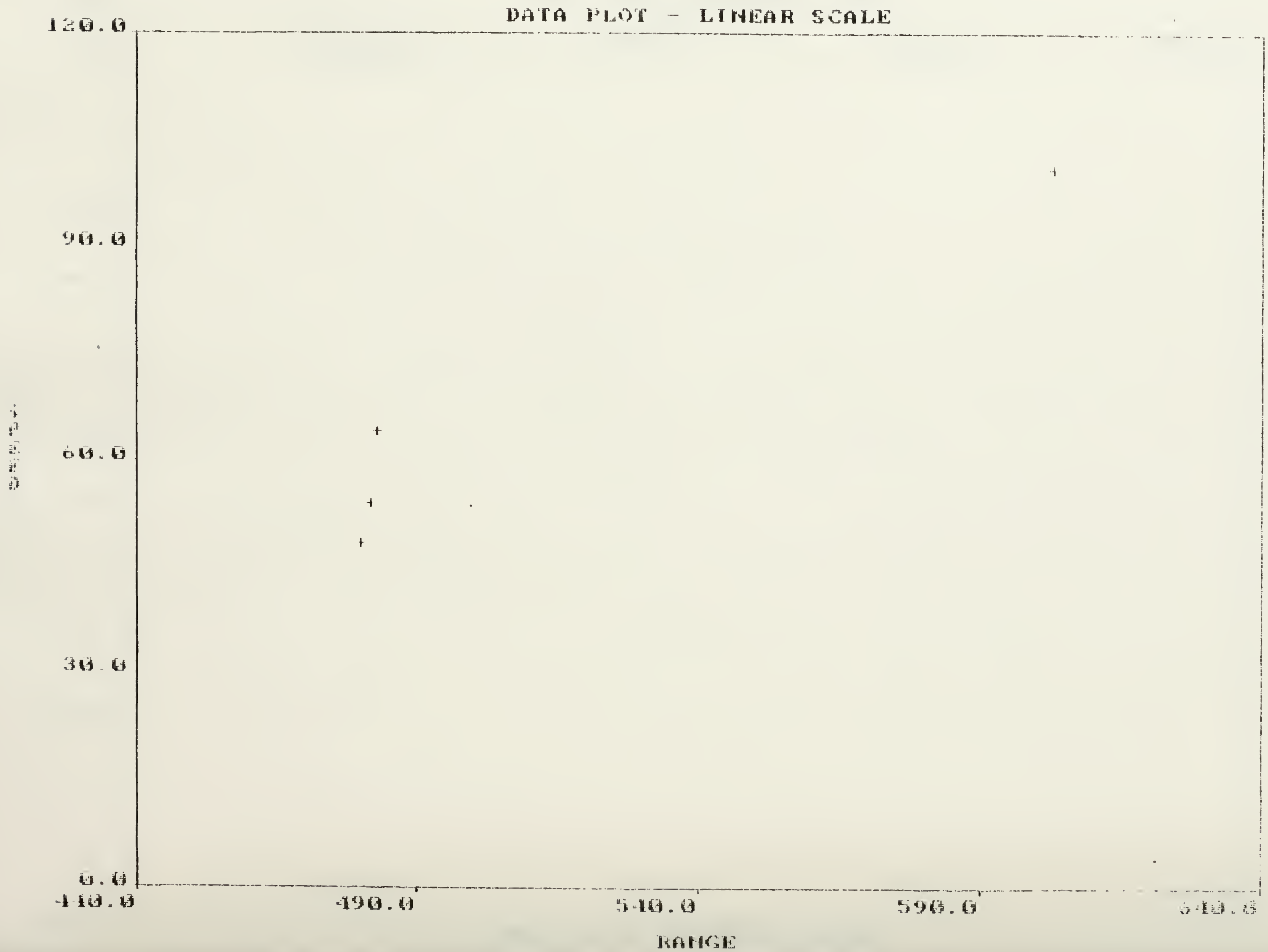
REGRESSION EQUATION PLOT - LINEAR SCALE
WEIGHT
150000.0
300000.0
450000.0
600000
40.0
60.0
80.0

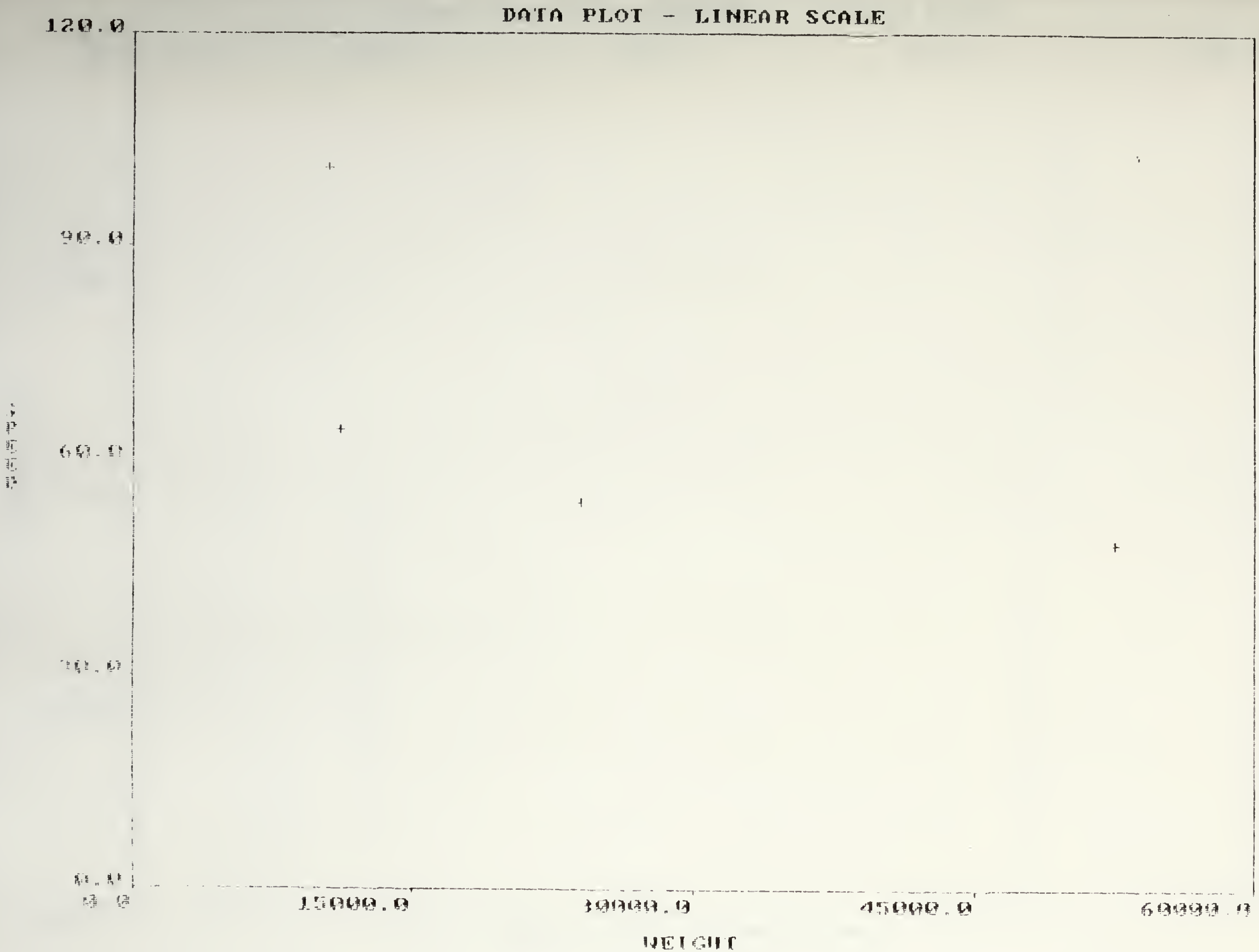


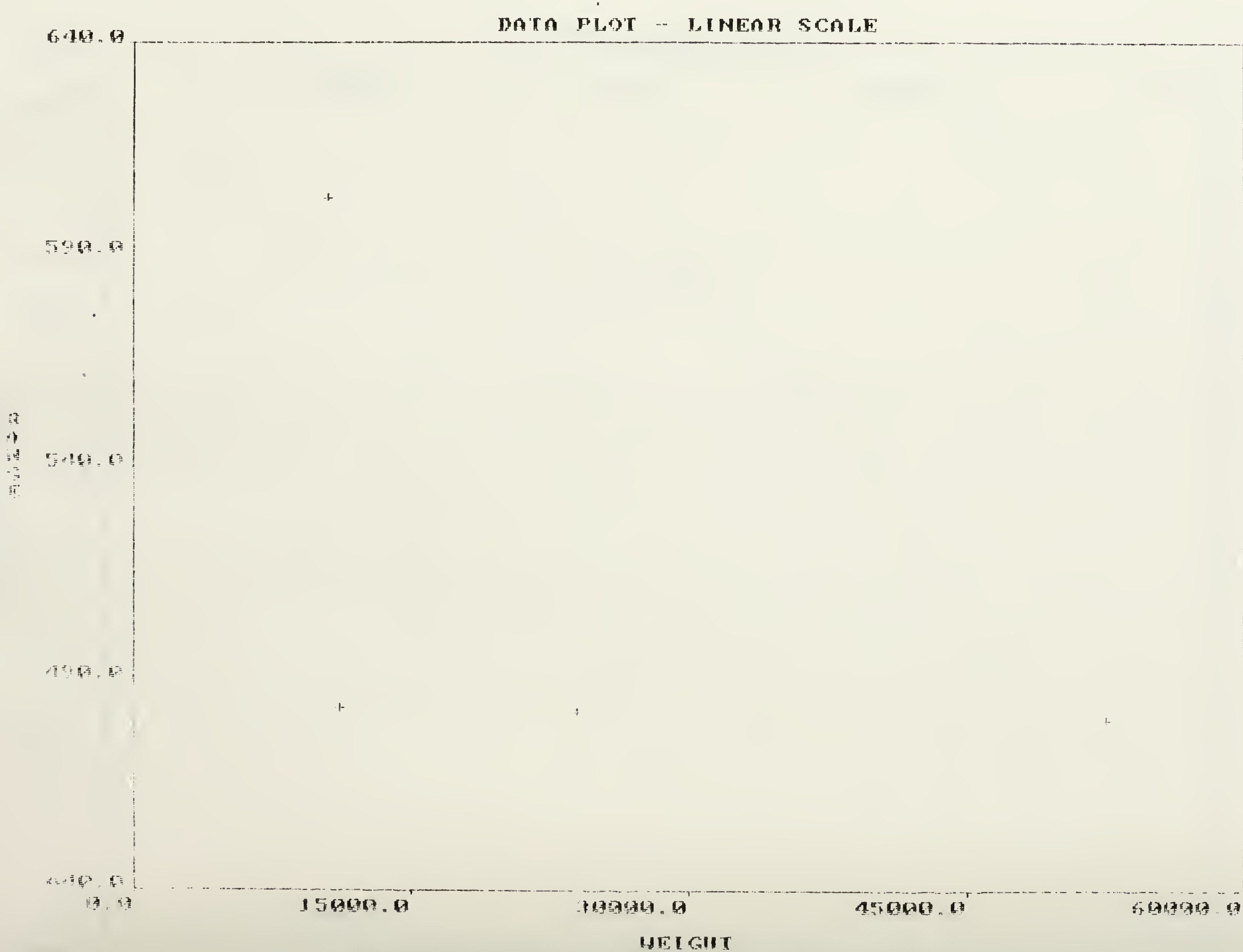
REGRESSION EQUATION PLOT - LINEAR SCALE
80.0
60.0
40.0
20.0
0.0
RATE COST
0.0
30.0
60.0
90.0
120.0
SPEED

REGRESSION EQUATION PLOT - LINEAR SCALE



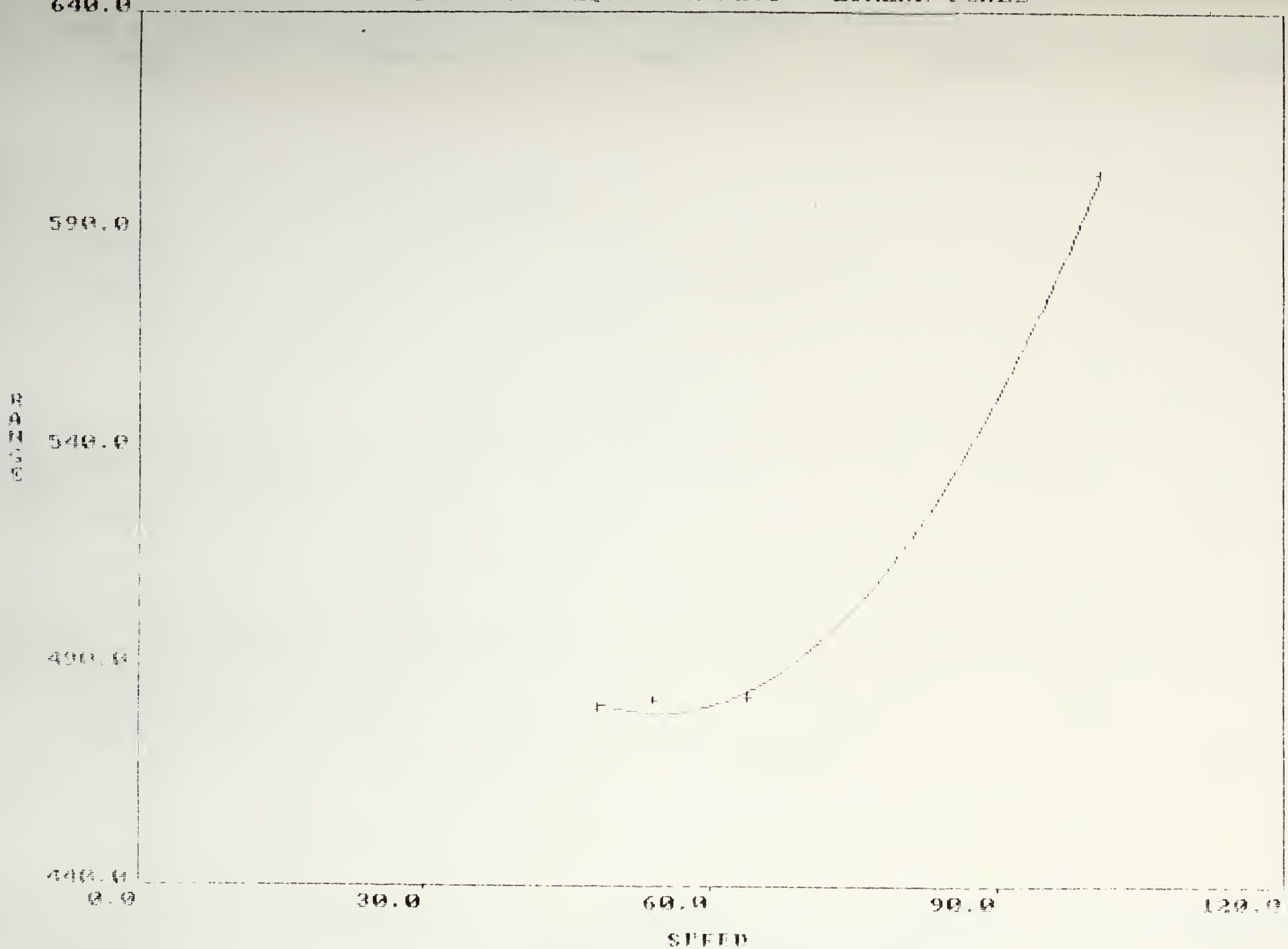

DATA PLOT - LINEAR SCALE
120.0
90.0
60.0
30.0
0.0
440.0
490.0
540.0
590.0
640.0
RANGE

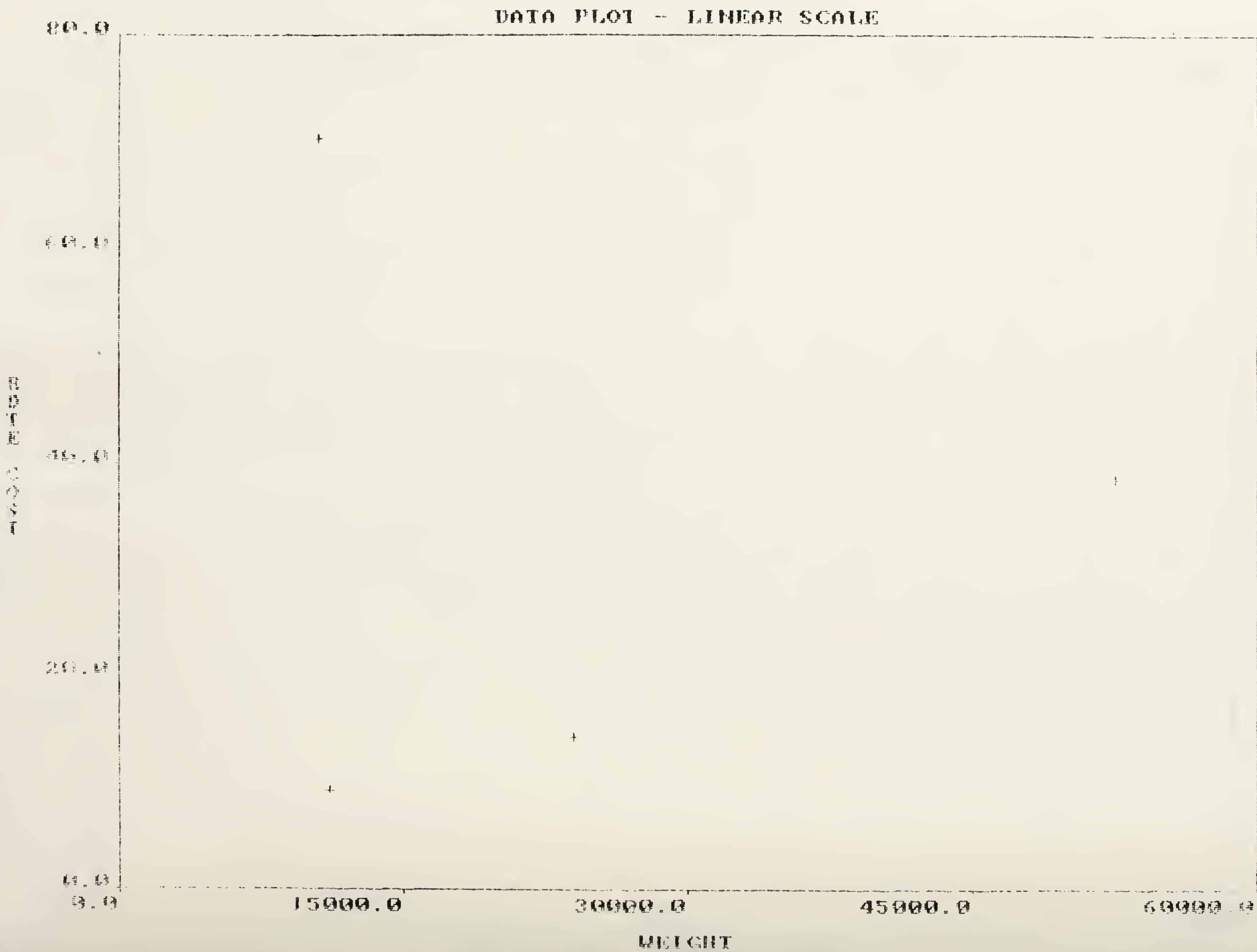

DATA PLOT - LINEAR SCALE
120.0
90.0
60.0
30.0
0.0
0.0
15000.0
30000.0
45000.0
60000.0
WEIGHT



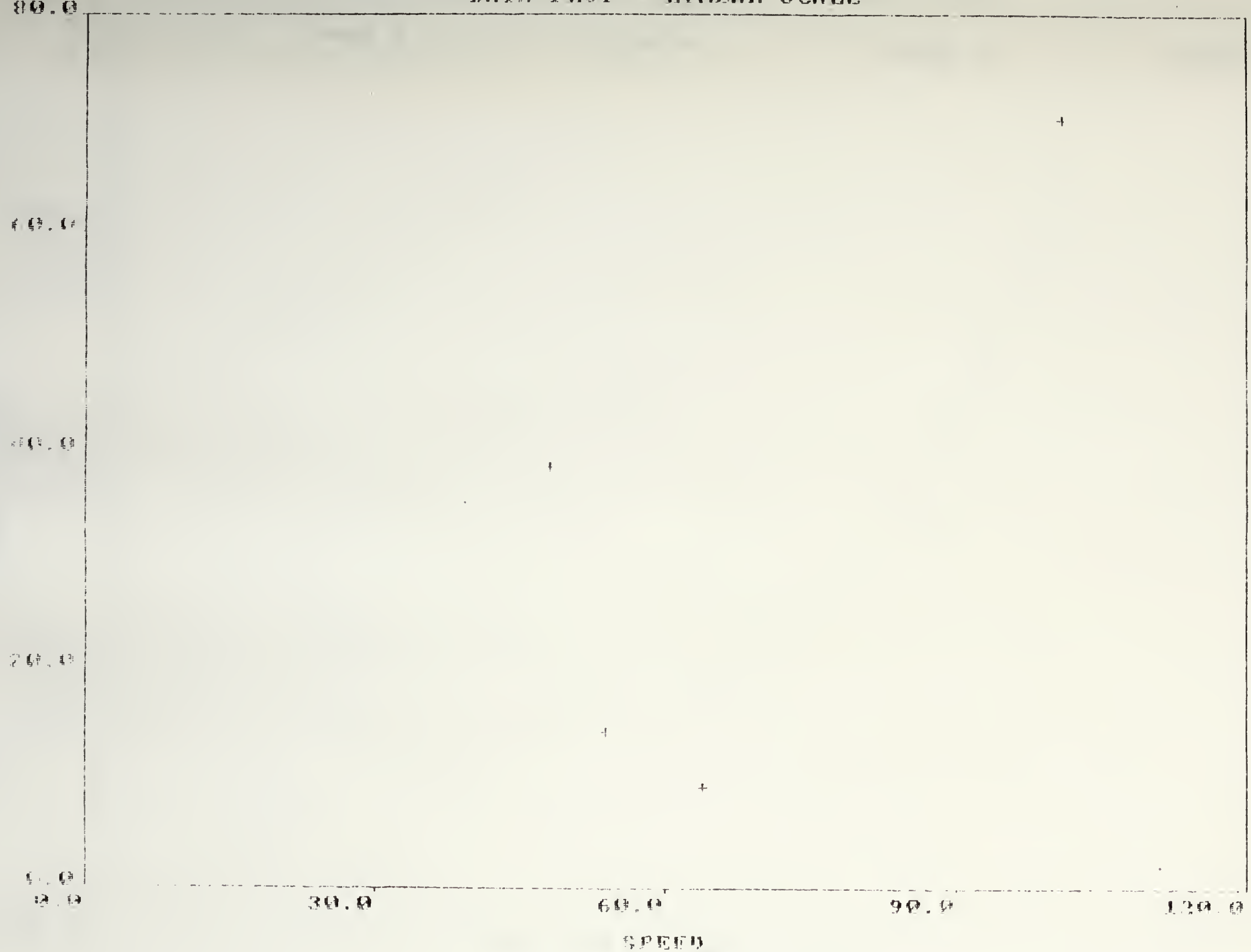
DATA PLOT - LINEAR SCALE
640.0
590.0
540.0
490.0
440.0
0.0
15000.0
30000.0
45000.0
60000.0
WEIGHT

REGRESSION EQUATION PLOT - LINEAR SCALE

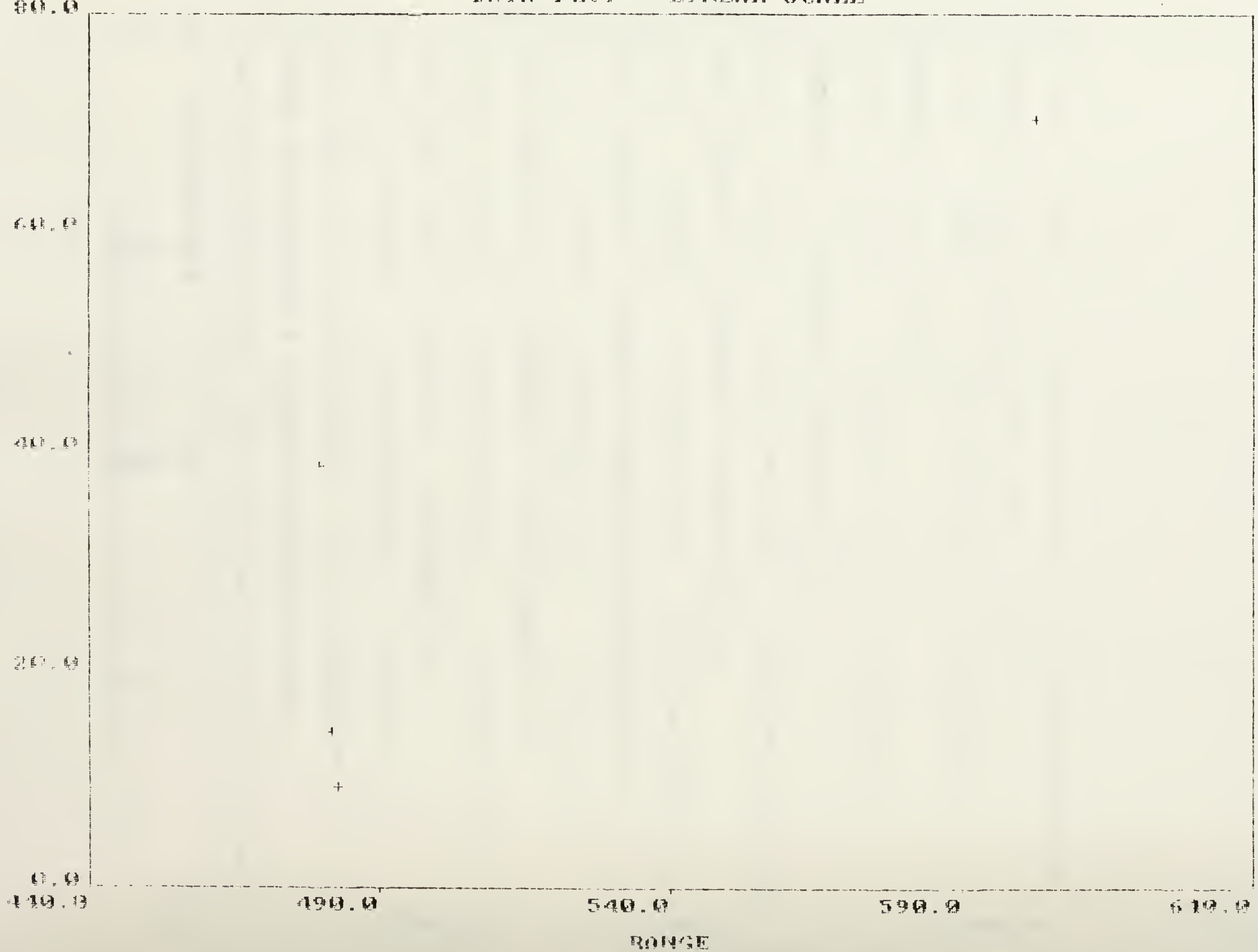



DATA PLOT - LINEAR SCALE
80.0
60.0
40.0
20.0
0.0
0.0
15000.0
30000.0
45000.0
60000.0
WEIGHT

DATA PLOT - LINEAR SCALE



DATA PLOT – LINEAR SCALE



APPENDIX C-PROCUREMENT CER DERIVATION

A. 1ST ITERATION

NUMBER OF OBSERVATIONS:7 (BFV,AAV7A1,M1A1,LCAC,M113,LAV,M60)

NUMBER OF VARIABLES:4 (RANGE,SPEED,WEIGHT,COSTS)

PROC COSTS= 1.1-.000051 WEIGHT + 1.07 e-9 WEIGHT^2pg.71

R^2.99 SE=.69 F-statistic=488 t-ratio=-2.71

PROC COSTS=-68.2 + 1.9SPEED - .013SPEED^2pg.73

R^2=.218 SE=9.6 F-statistic=.58 t-ratio=1.033

PROC COSTS=55.7 - .203RANGE + .000186 RANGE^2pg.75

R^2=.99 SE=.94 F-statistic=267 t-ratio=-11.4

PROC COSTS=15.1-.05RANGE+.15SPEED+.000043WEIGHT pg.75,74,72

R^2=.99 SE=.99 F-statistic=158 t-ratio=-5R/5S/1.9W

PROC COSTS=24 - .069RANGE+.174SPEED pg.76,70

R^2=.98 SE=1.3 F-statistic=138 t-ratio=-16.4R/5.5S

RANGE=1514 -30.9SPEED +.215SPEED^2pg.70

R^2=.308 SE=130 F-statistic=.89 t-ratio=-1.97

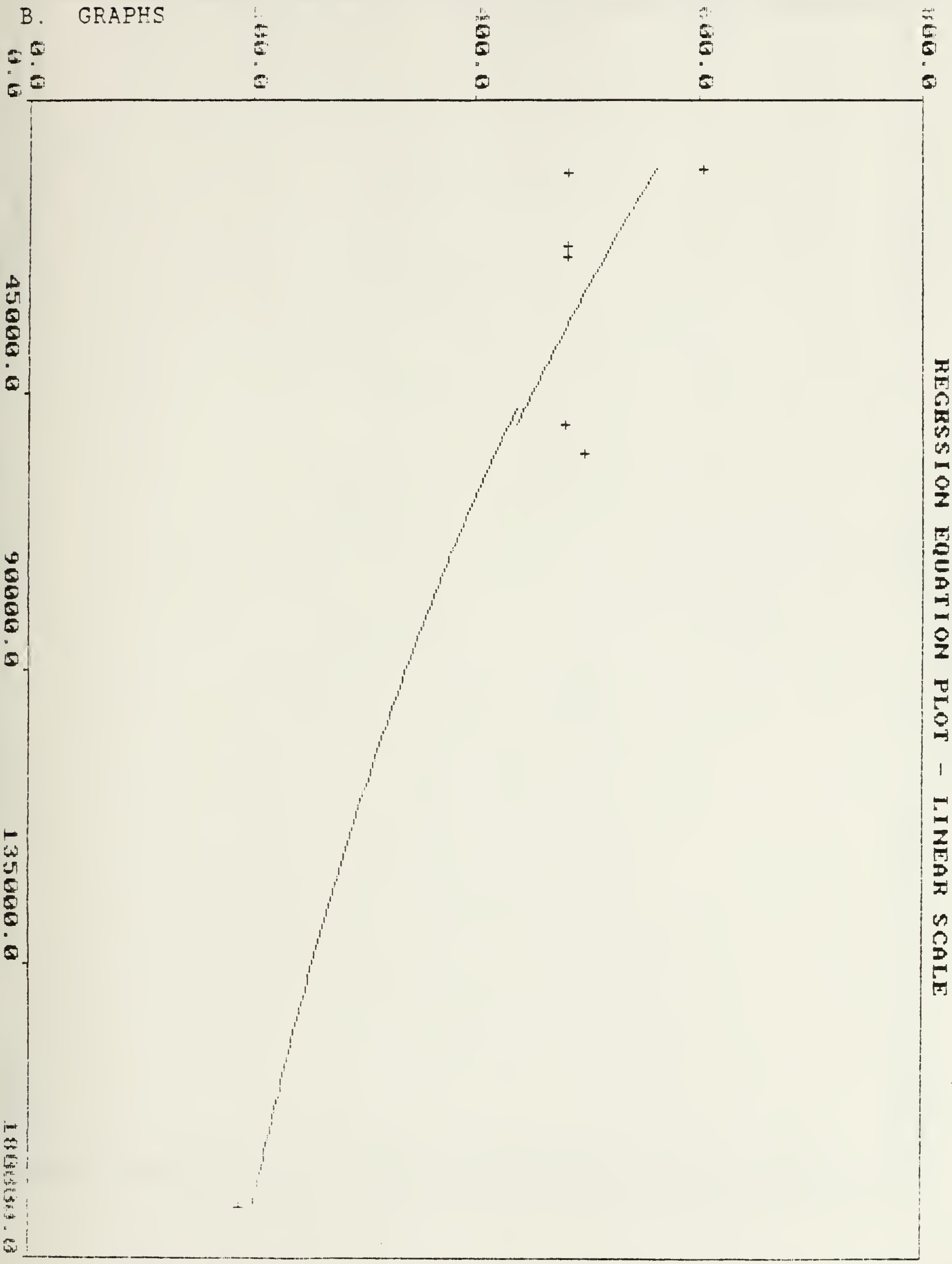
RANGE=$e^{(6.4-.000006\text{WEIGHT})}$pg.69

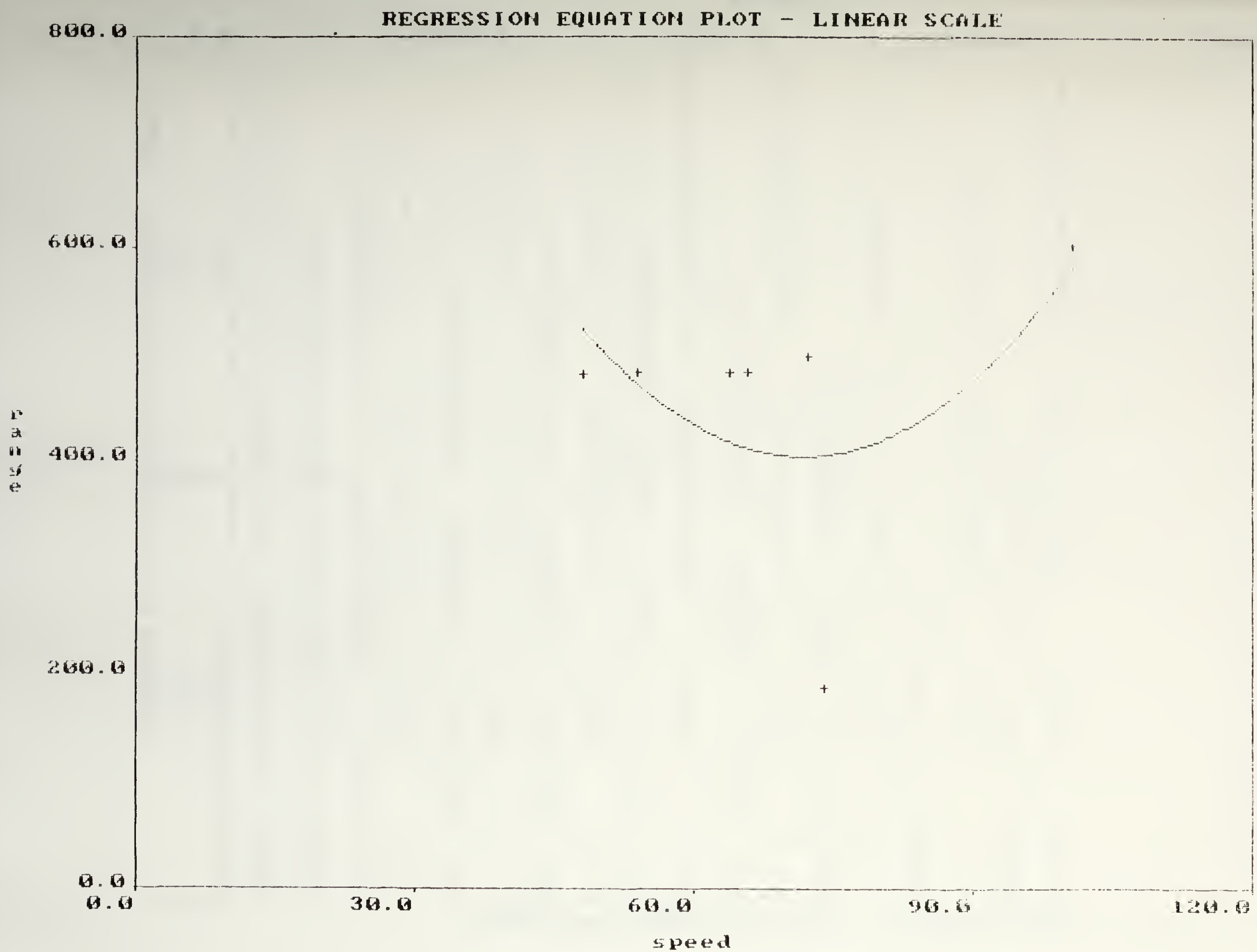
R^2=.90 SE=62.2 F-statistic=47 t-ratio=-6.8

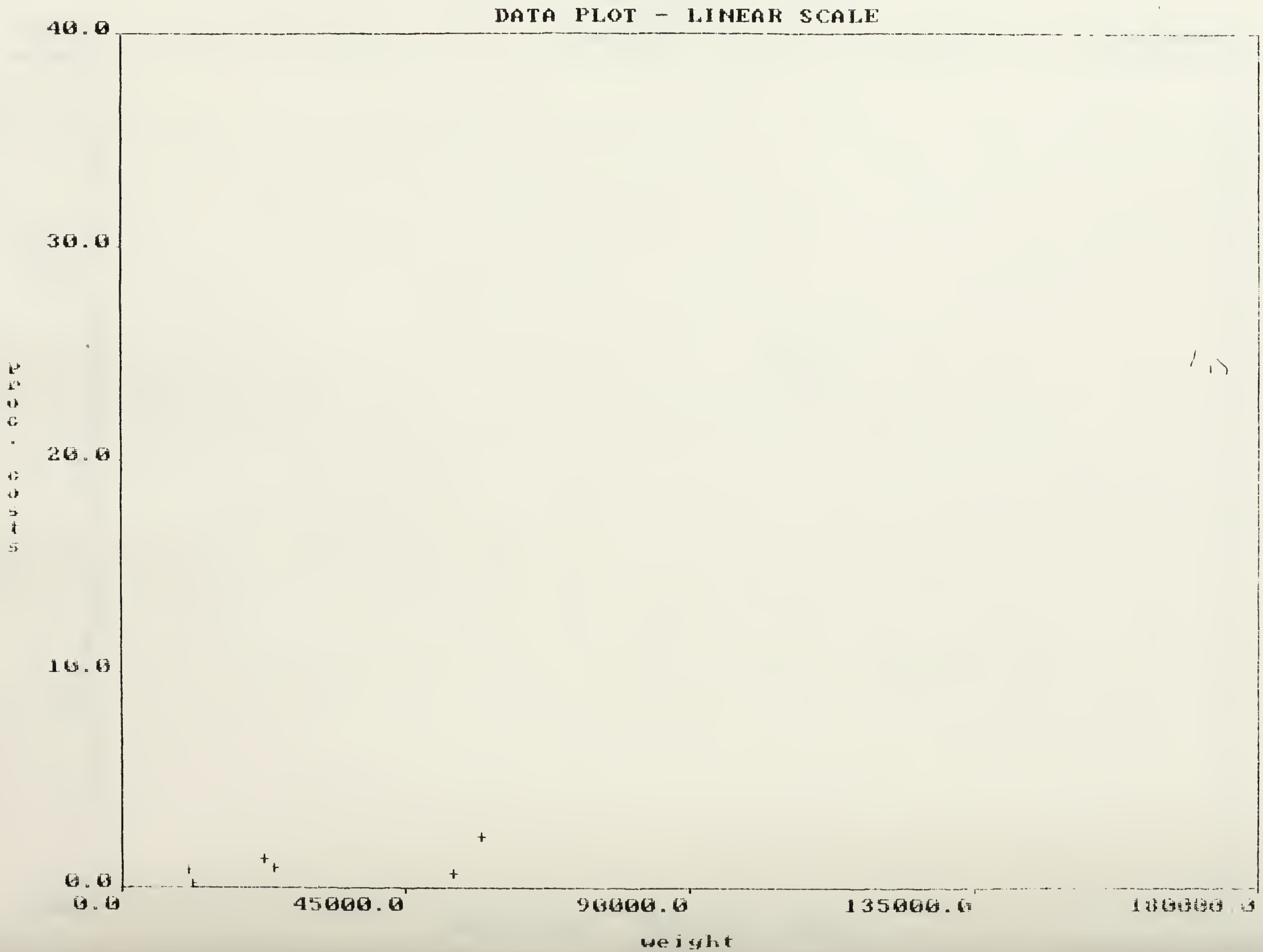
RANGE=$e^{(6.3+.001\text{SPEED}-.000006\text{WEIGHT})}$pg.69-70

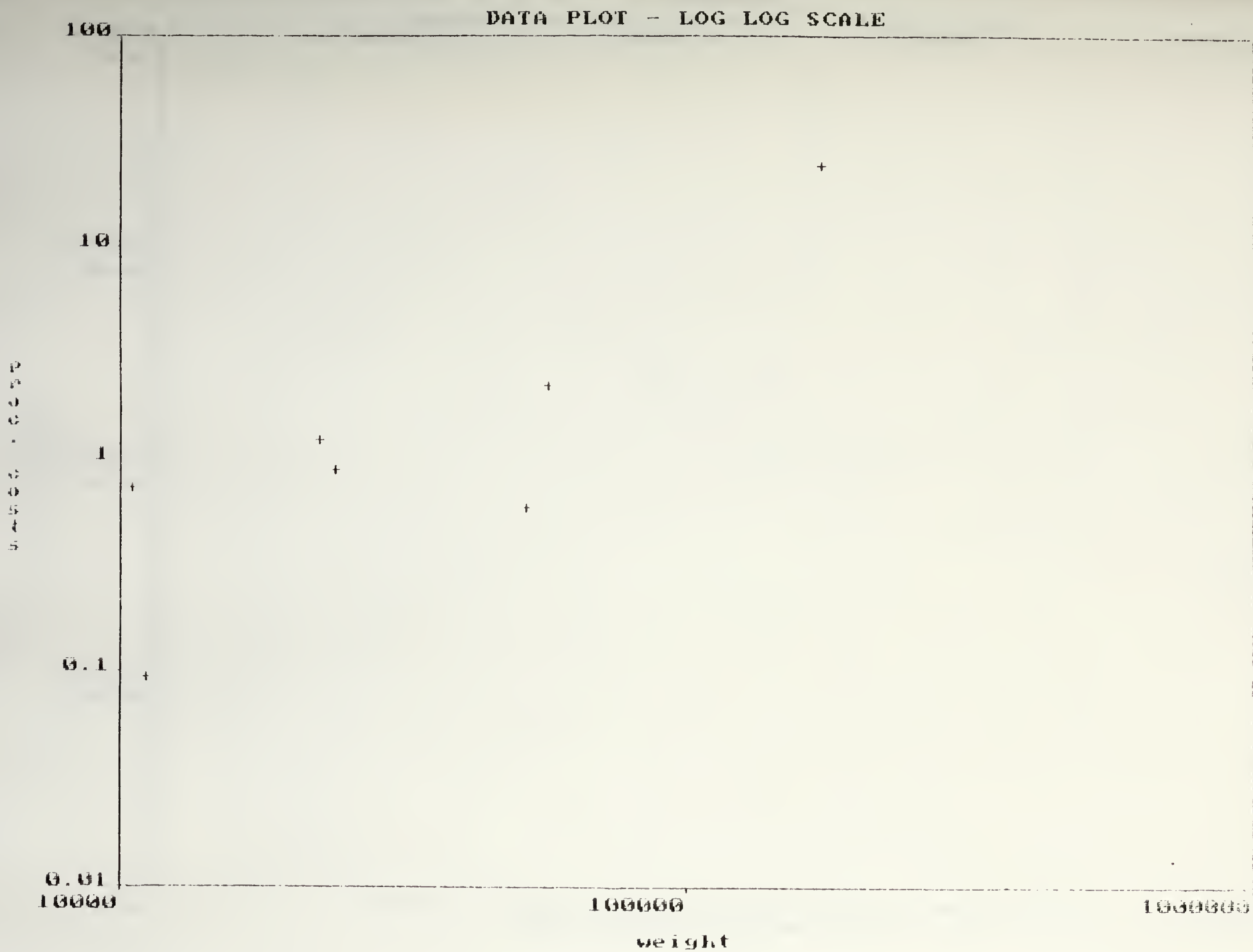
R^2=.907 SE=66.7 F-statistic=19.5 t-ratio=.4S/-6.2W

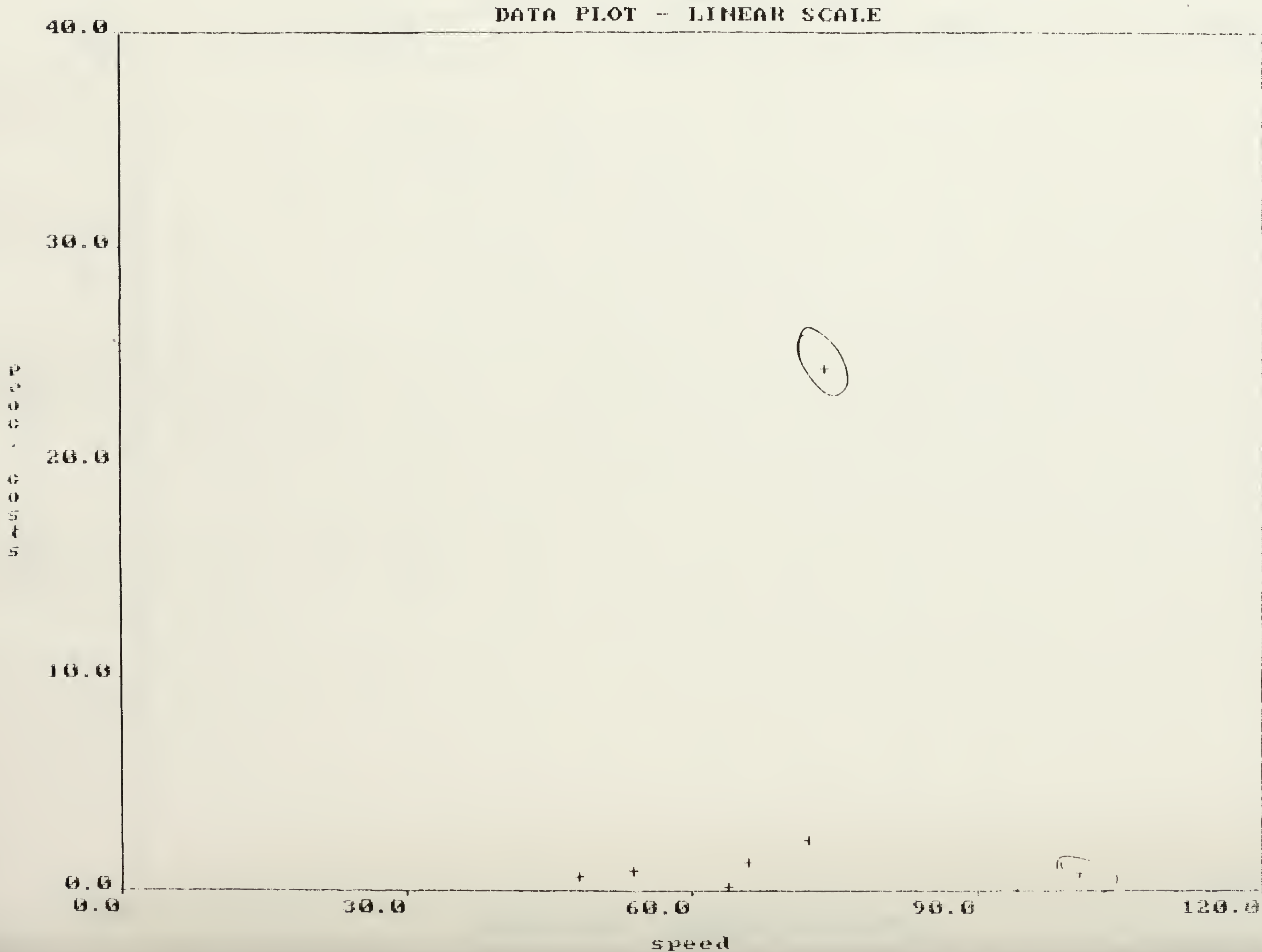
B. GRAPHS

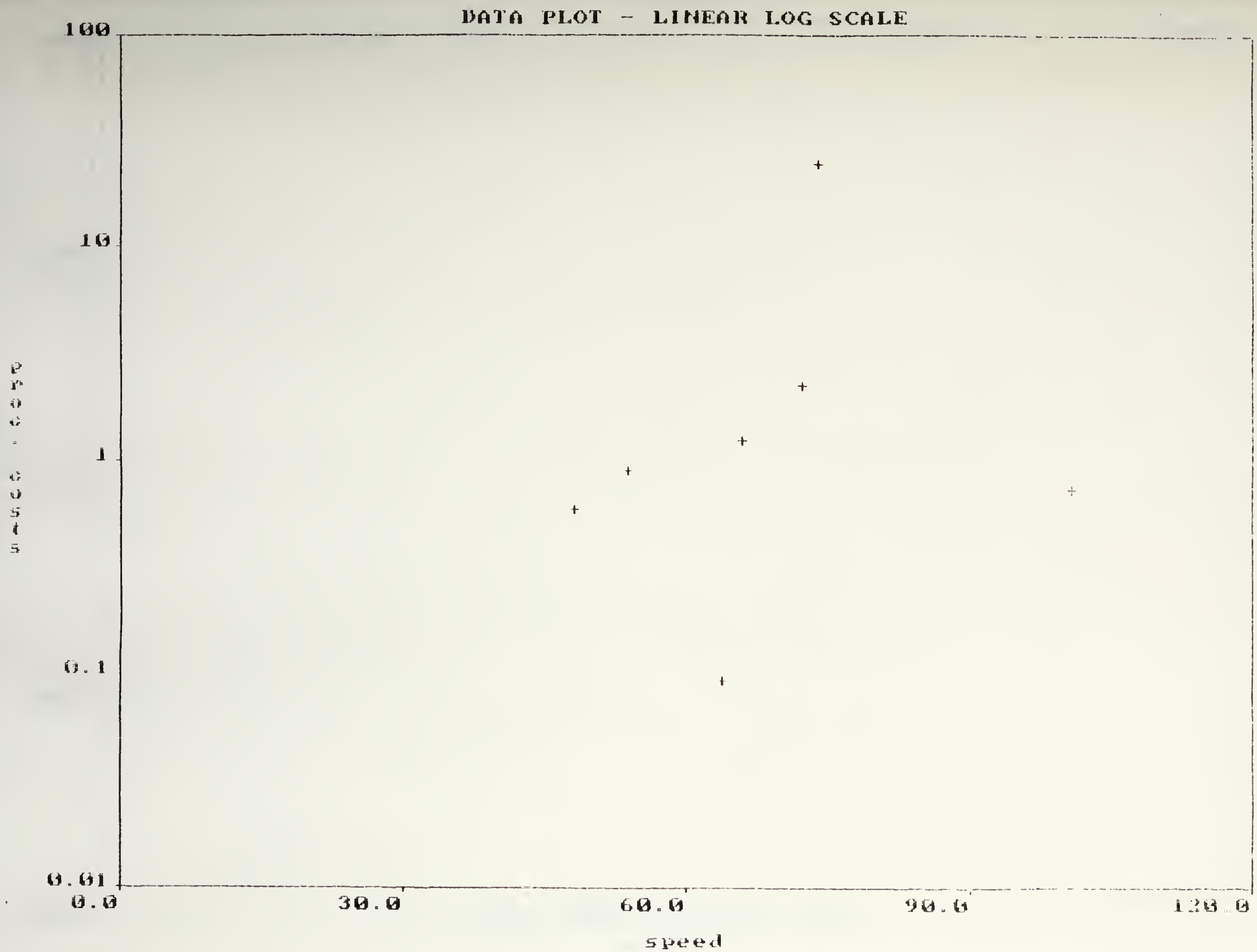

REGRSSION EQUATION PLOT - LINEAR SCALE
0.0
45000.0
90000.0
135000.0
weight
0.0
400.0

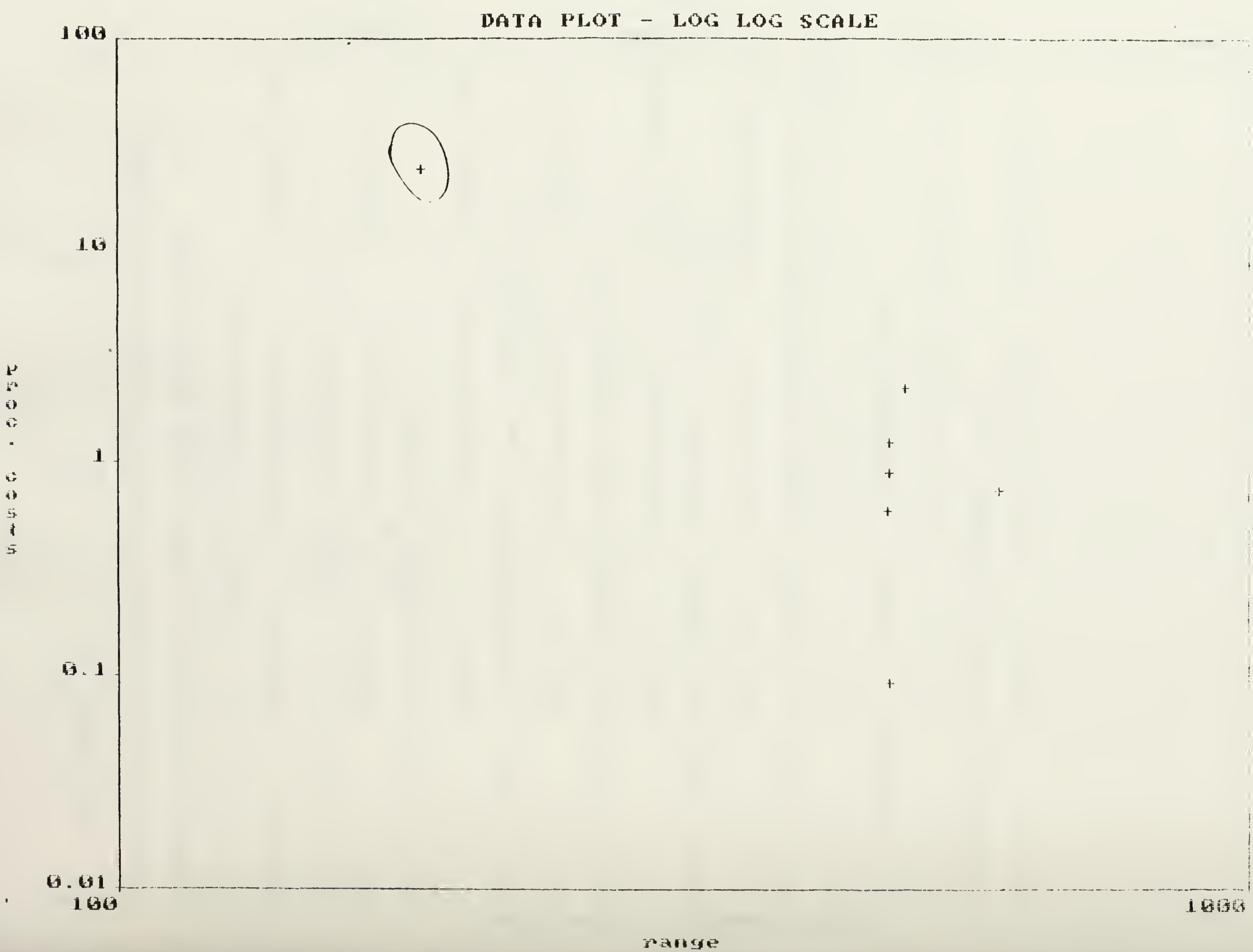

REGRESSION EQUATION PLOT - LINEAR SCALE
800.0
600.0
400.0
200.0
0.0
range
0.0
30.0
60.0
90.0
120.0
speed

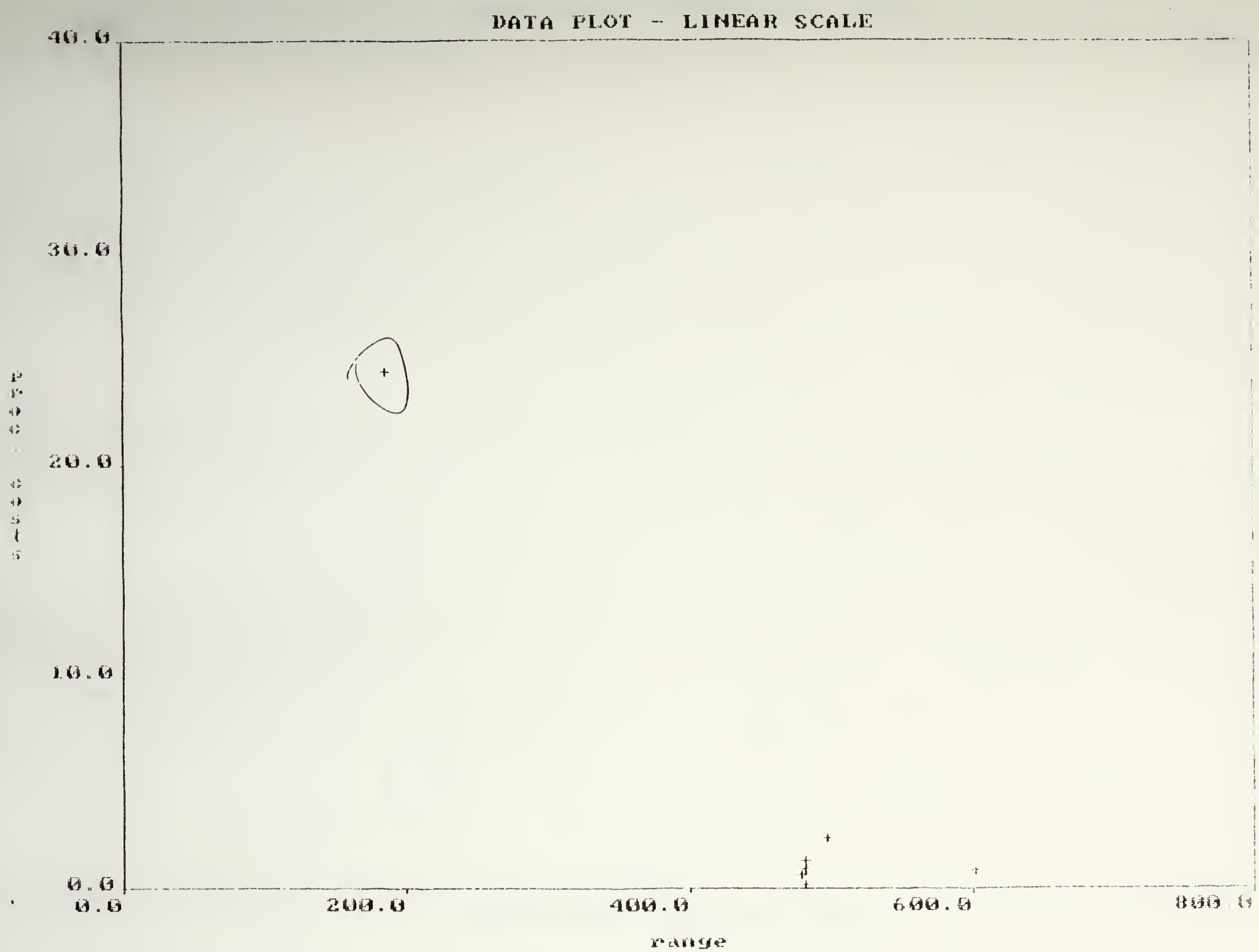

DATA PLOT - LINEAR SCALE
40.0
30.0
20.0
10.0
0.0
proc. costs
0.0
45000.0
90000.0
135000.0
180000.0
weight


DATA PLOT - LOG LOG SCALE
100
10
1
0.1
0.01
10000
100000
1000000
weight
proc. costs


DATA PLOT - LINEAR SCALE
40.0
30.0
20.0
10.0
0.0
0.0
30.0
60.0
90.0
120.0
speed
prod. costs


DATA PLOT - LINEAR LOG SCALE
100
10
1
0.1
0.01
0.0
30.0
60.0
90.0
120.0
speed
proc. costs


DATA PLOT - LOG LOG SCALE
100
10
1
0.1
0.01
proc. costs
100
1000
range


DATA PLOT - LINEAR SCALE
40.0
30.0
20.0
10.0
0.0
proc costs
0.0
200.0
400.0
600.0
800.0
range

C. 2ND ITERATION

NUMBER OF OBSERVATIONS:6 (BFV,AAV7A1,M1A1,M113,LAV,M60)

NUMBER OF VARIABLES:4 (RANGE,SPEED,WEIGHT,COSTS)

PROC COSTS=2.25-.009RANGE+.048SPEED pg.80-81

R^2=.286 SE=.79 F-statistic=.6 t-ratio=-1R/1S

PROC COSTS=-255.4 +.96RANGE-.00088RANGE^2 pg.82

R^2=.72 SE=.49 F-statistic=3.8 t-ratio=2.77

PROC COSTS=-5.3+.173SPEED-.001SPEED^2 pg.83

R^2=.245 SE=.81 F-statistic=.48 t-ratio=.974

PROC COSTS=.23+.000029WEIGHT-1.02e-10WEIGHT^2 pg.79

R^2=.378 SE=.74 F-statistic=.913 t-ratio=.26

PROC COSTS=8.14e-24RANGE$^{6.4}$WEIGHT$^{1.3}$ pg.85,87,88

R^2.57 SE=.68 F-statistic=2.01 t-ratio=1.2R/2W

PROC COSTS=9.08e-12SPEED^{2}2.7WEIGHT$^{1.3}$ pg.86-87,89

R^2=.645 SE=.628 F-statistic=2.7 t-ratio=1.5S/2.3W

PROC COSTS=4.6-.017RANGE+.06SPEED+.00003WEIGHT pg.90,86,87

R^2=.755 SE=.569 F-statistic=2 t-ratio=-1.2R/1.6S/2W

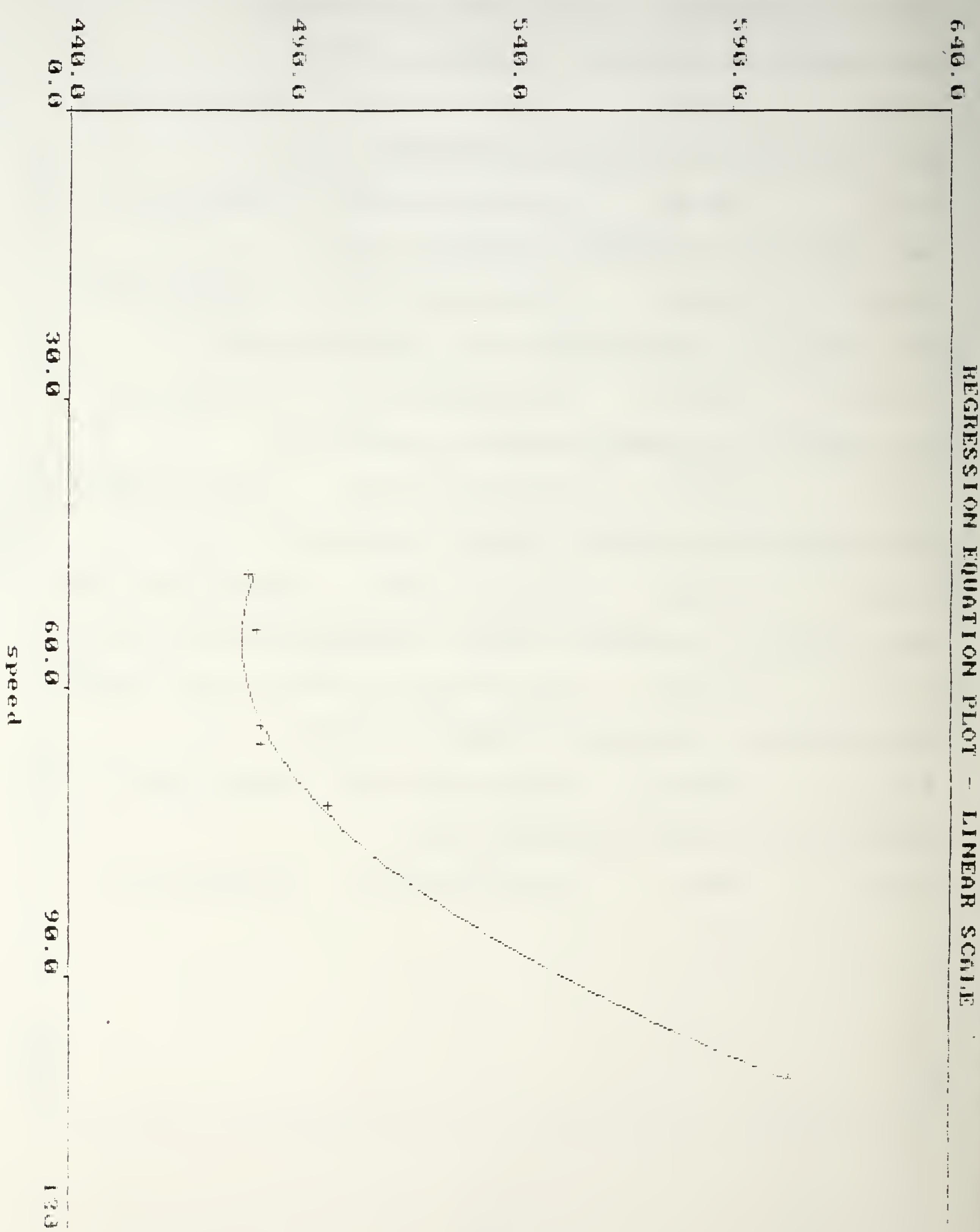
PROC COSTS=6.5-.017RANGE+.047SPEED pg.78,84

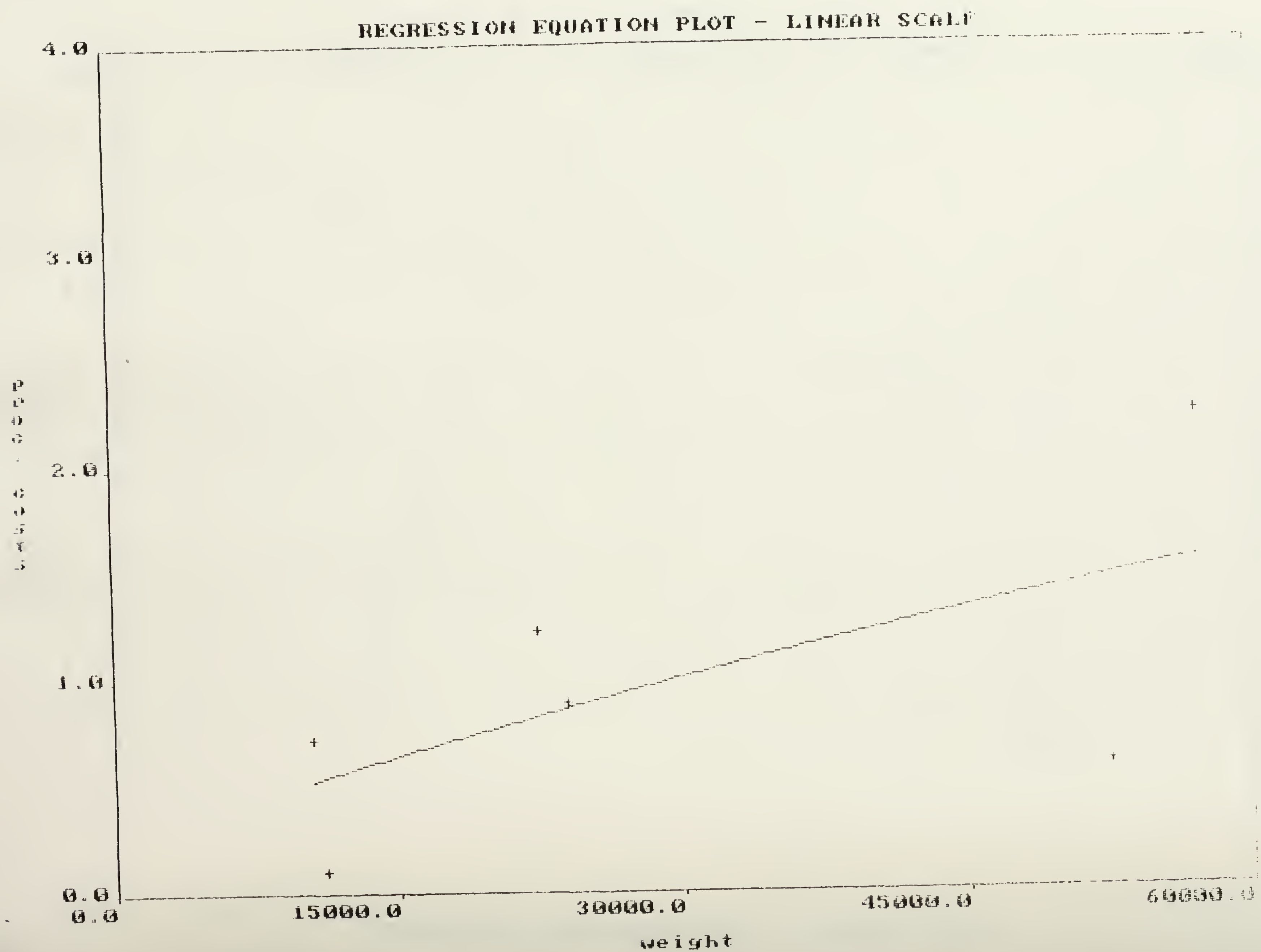
R^2=.214 SE=.831 F-statistic=.409 t-ratio=-.9R/.9S

RANGE=658.4-6.5SPEED+.059SPEED^2 pg.84

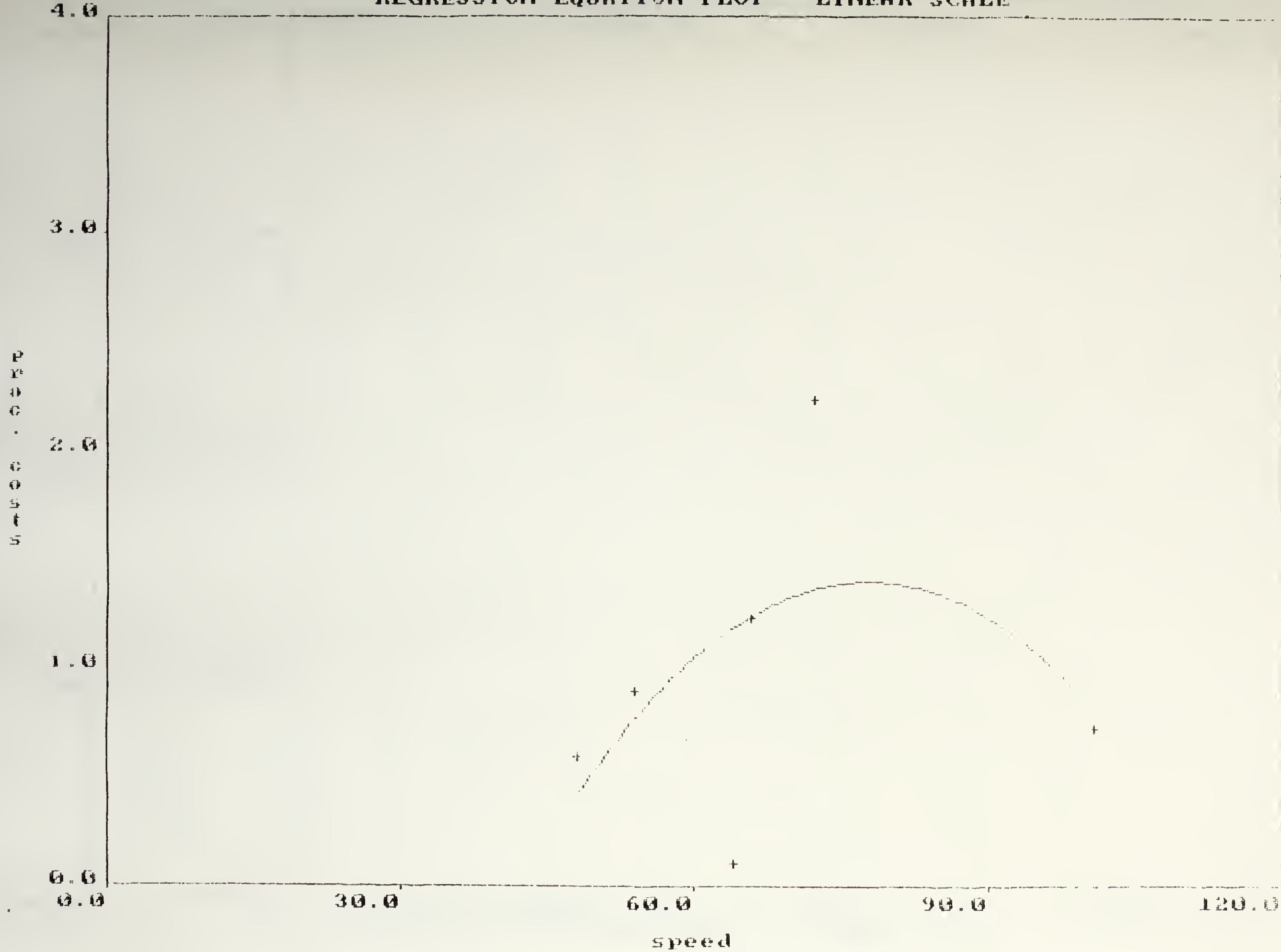
R^2=.99 SE=2.7 F-statistic=779 t-ratio=-10.9

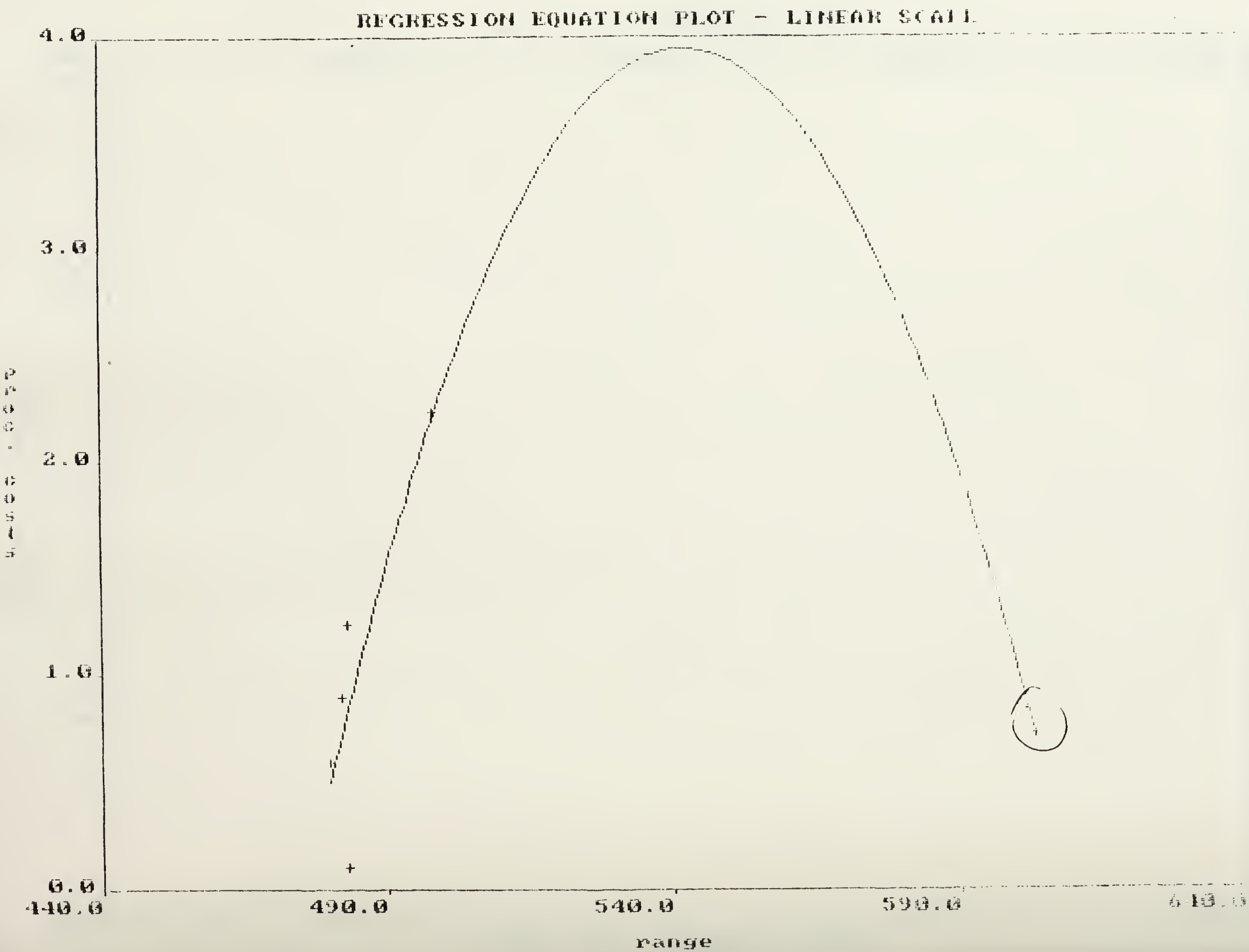
D. GRAPHS

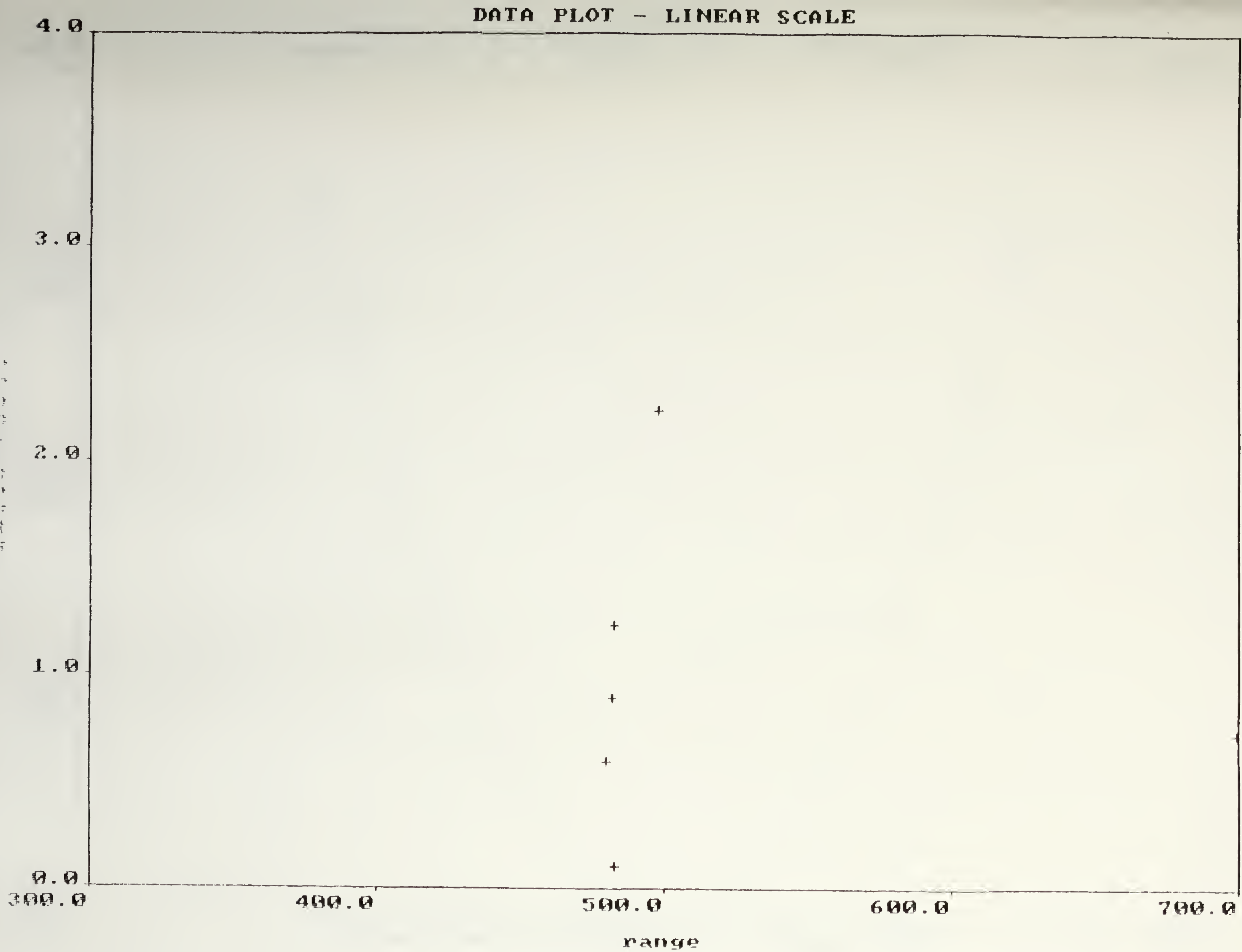

REGRESSION EQUATION PLOT - LINEAR SCALE
range
640.0
590.0
540.0
490.0
440.0
0.0
30.0
60.0
90.0
speed

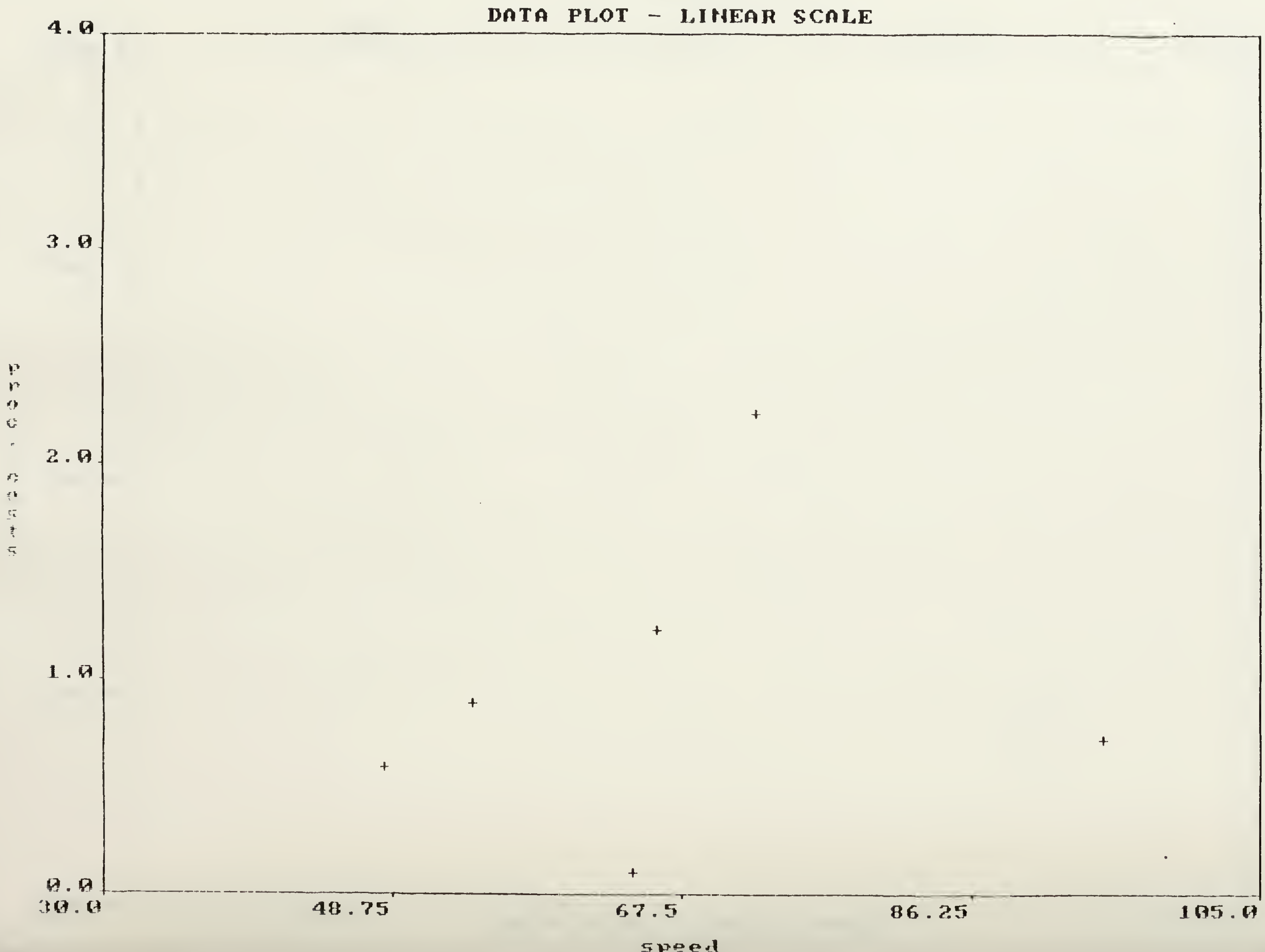

REGRESSION EQUATION PLOT - LINEAR SCALE
4.0
3.0
2.0
1.0
0.0
0.0
15000.0
30000.0
45000.0
60000.0
weight

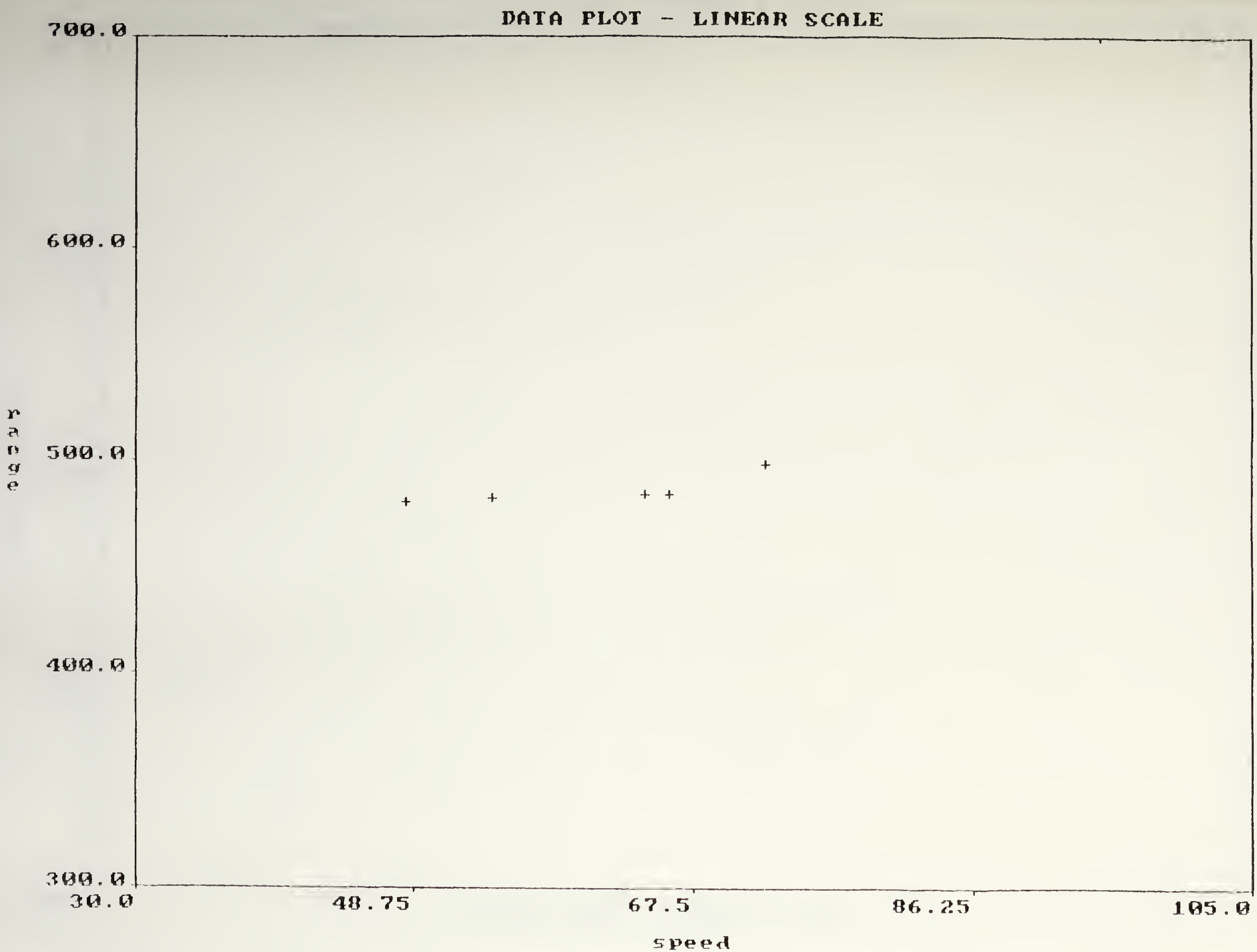
REGRESSION EQUATION PLOT - LINEAR SCALE

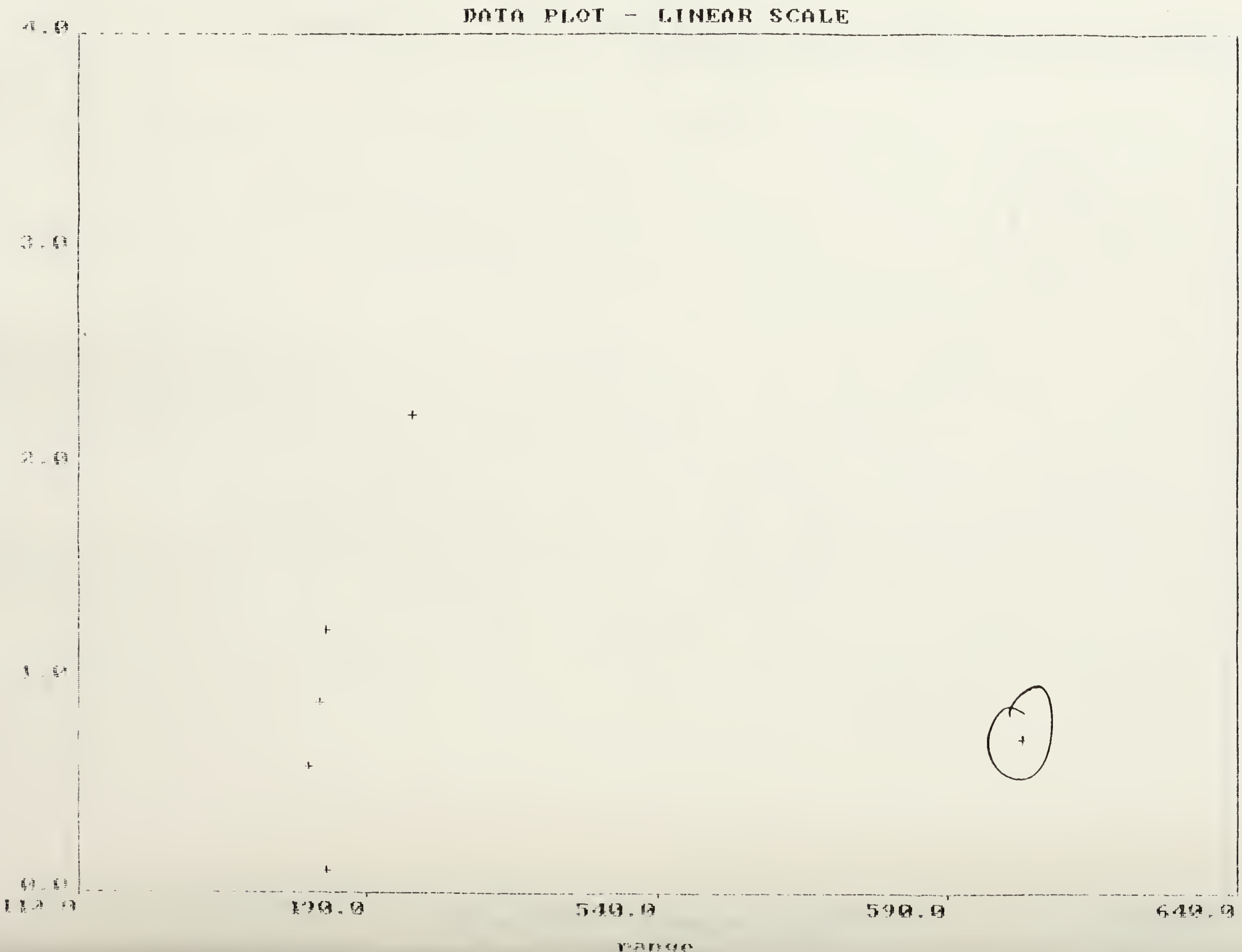



REGRESSION EQUATION PLOT - LINEAR SCALE
4.0
3.0
2.0
1.0
0.0
440.0
490.0
540.0
590.0
range

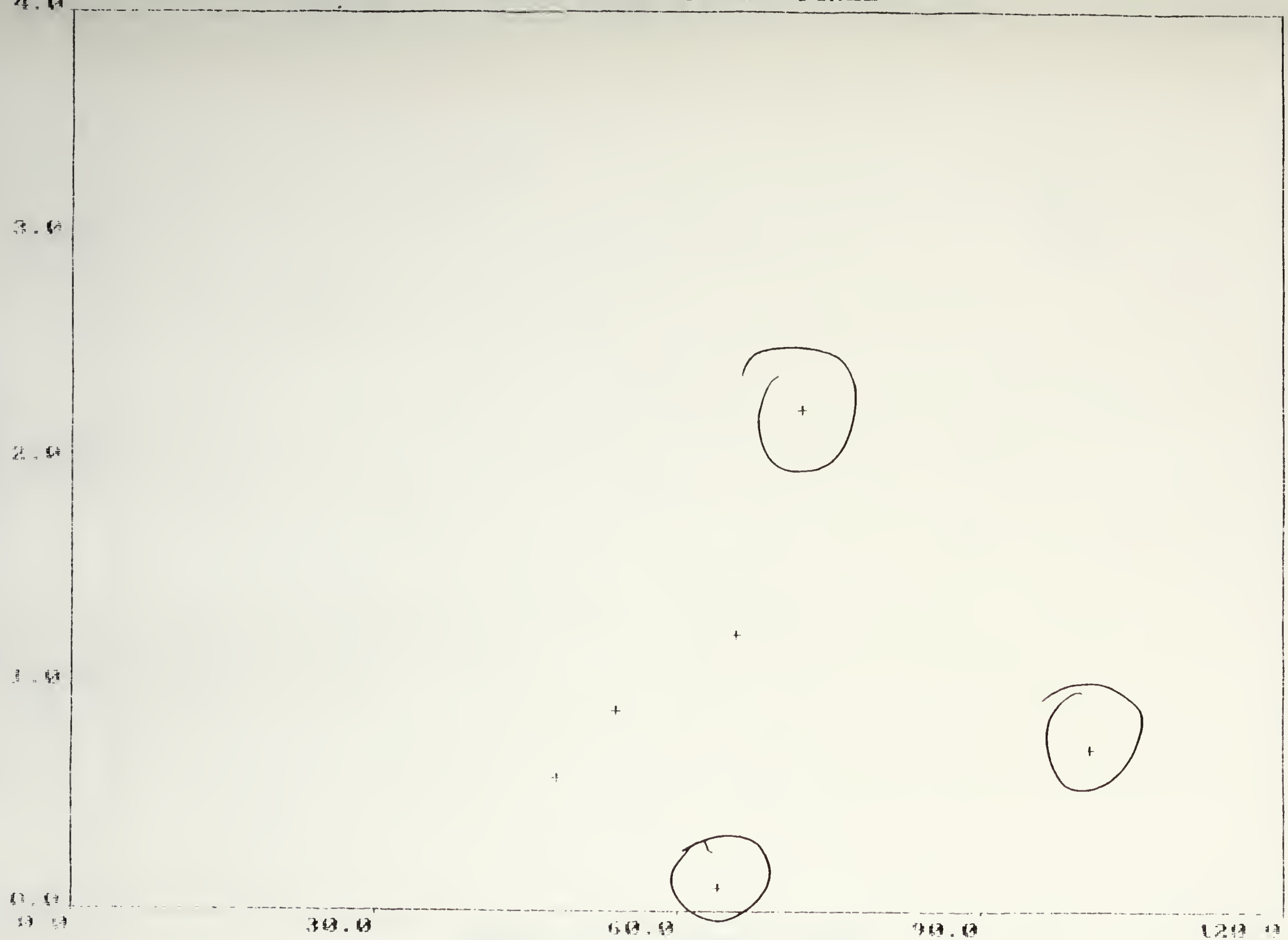

DATA PLOT - LINEAR SCALE
4.0
3.0
2.0
1.0
0.0
300.0
400.0
500.0
600.0
700.0
range


DATA PLOT - LINEAR SCALE
4.0
3.0
2.0
1.0
0.0
30.0
48.75
67.5
86.25
105.0
speed

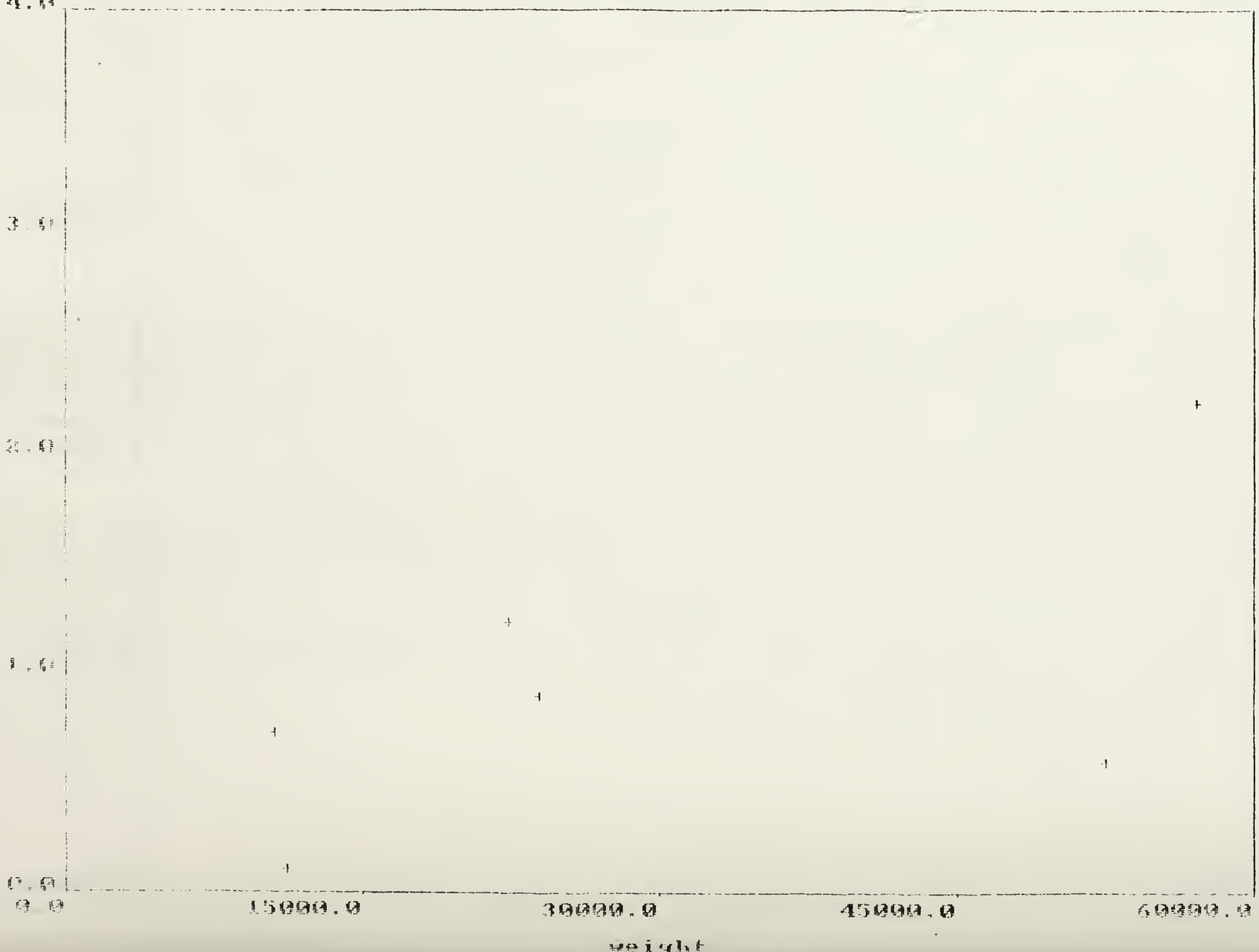

DATA PLOT - LINEAR SCALE
700.0
600.0
500.0
400.0
300.0
range
30.0
48.75
67.5
86.25
105.0
speed


DATA PLOT - LINEAR SCALE
4.0
3.0
2.0
1.0
0.0
490.0
540.0
590.0
640.0
range

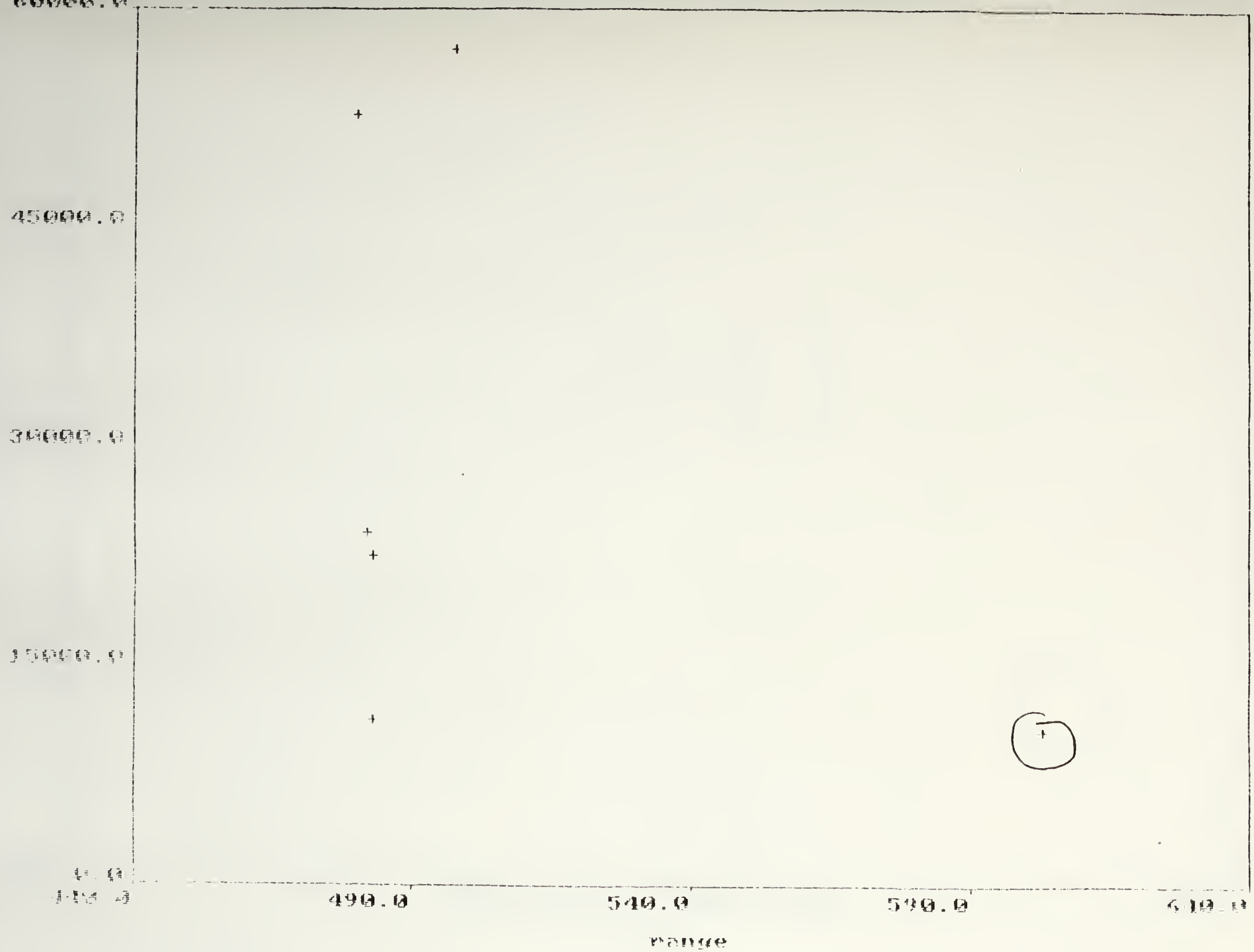
DATA PLOT - LINEAR SCALE

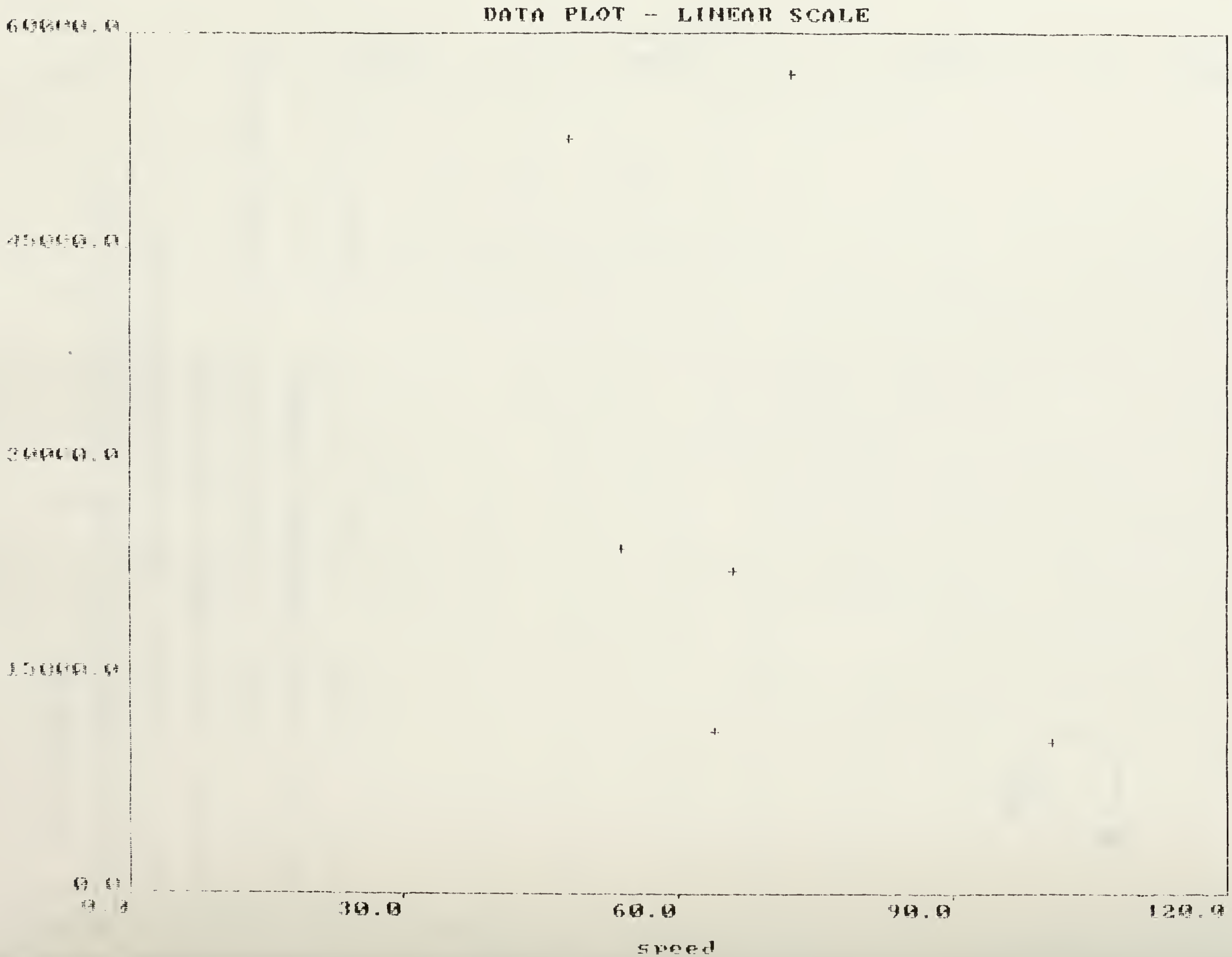


DATA PLOT - LINEAR SCALE

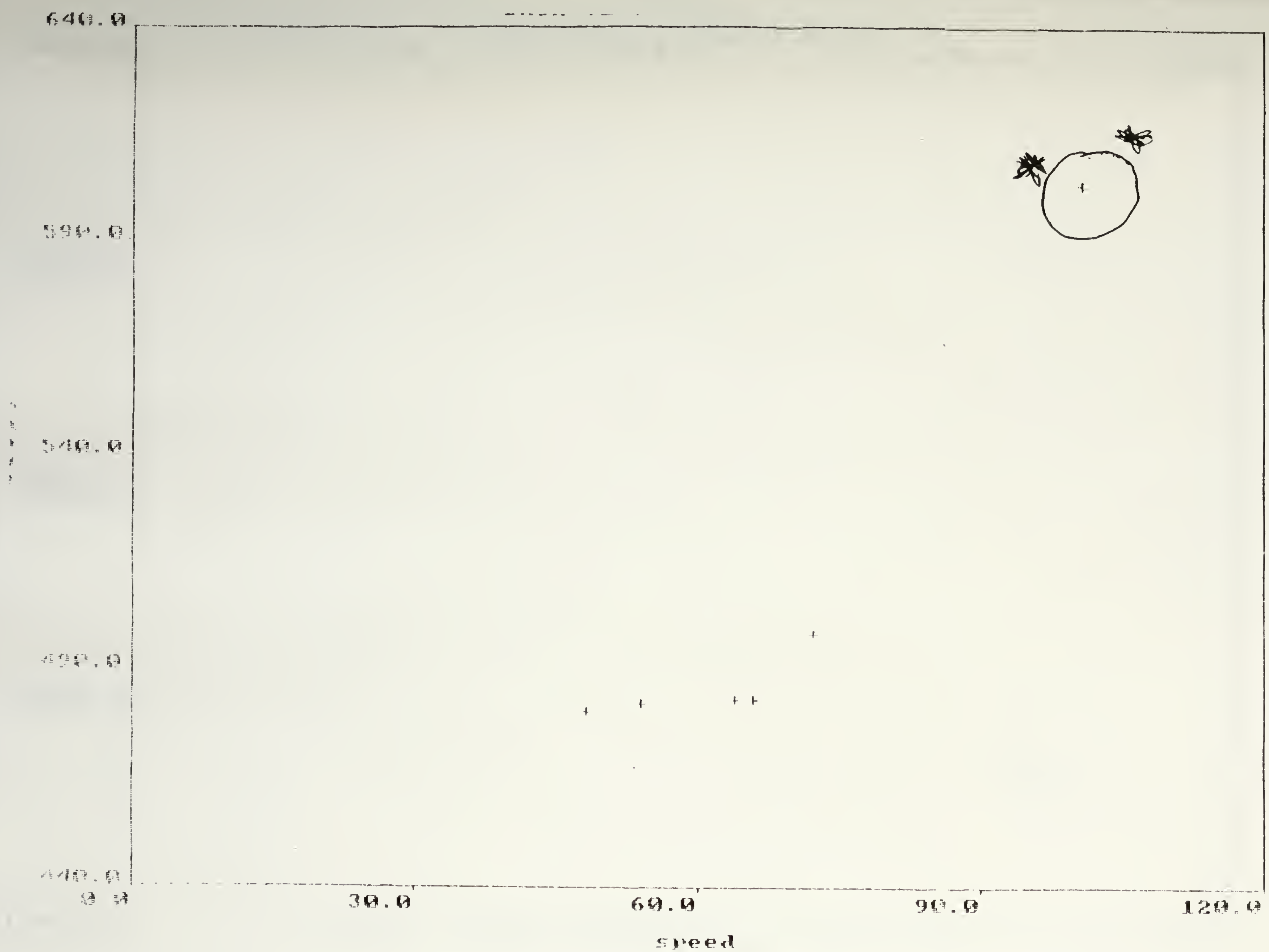


DATA PLOT - LINEAR SCALE





DATA PLOT - LINEAR SCALE
60000.0
45000.0
30000.0
15000.0
0.0
0.0
30.0
60.0
90.0
120.0
speed


640.0
590.0
540.0
490.0
440.0
0.0
30.0
60.0
90.0
120.0
speed

E. 3RD ITERATION

NUMBER OF OBSERVATIONS:5 (BFV,AAV7A1,M1A1,M113,M60)

NUMBER OF VARIABLES:4 (RANGE,SPEED,WEIGHT,COSTS)

PROC COSTS= -37.9+.08RANGE+.00001WEIGHT

R^2=.759   SE=.556   F-statistic=3.15   t-ratio=1.77R/.59W

PROC COSTS=-49.731+.106RANGE-.012SPEED

R^2=.726   SE=.593   F-statistic=2.65   t-ratio=1.6R/-.25S

APPENDIX D-OPERATING AND SUPPORT CER DERIVATION

A. 1ST ITERATION

NUMBER OF OBSERVATIONS:3 (AAV7A1,M113,LAV)

NUMBER OF VARIABLES:4 (RANGE,SPEED,WEIGHT,COST)

SPEED=-109.4+.349RANGE pg.93

R^2=.96   SE=6.8   F-statistic=25.3   t-ratio=5

SPEED=11187.8WEIGHT$^{-.53}$ pg.94

R^2=.56   SE=24.4   F-statistic=1.3   t-ratio=-1.5

RANGE=2334.4WEIGHT$^{-.157}$ pg.95

R^2=.32   SE=81.3   F-statistic=.46   t-ratio=-.68

O&S COSTS=567541.6WEIGHT$^{-.61}$ pg.96

R^2=.51   SE=772.6   F-statistic=1.04   t-ratio=-1.02

O&S COSTS=e$^{(6.26+.016SPEED)}$ pg.97

R^2=1   SE=1   F-statistic=2.19e+5   t-ratio=468.2

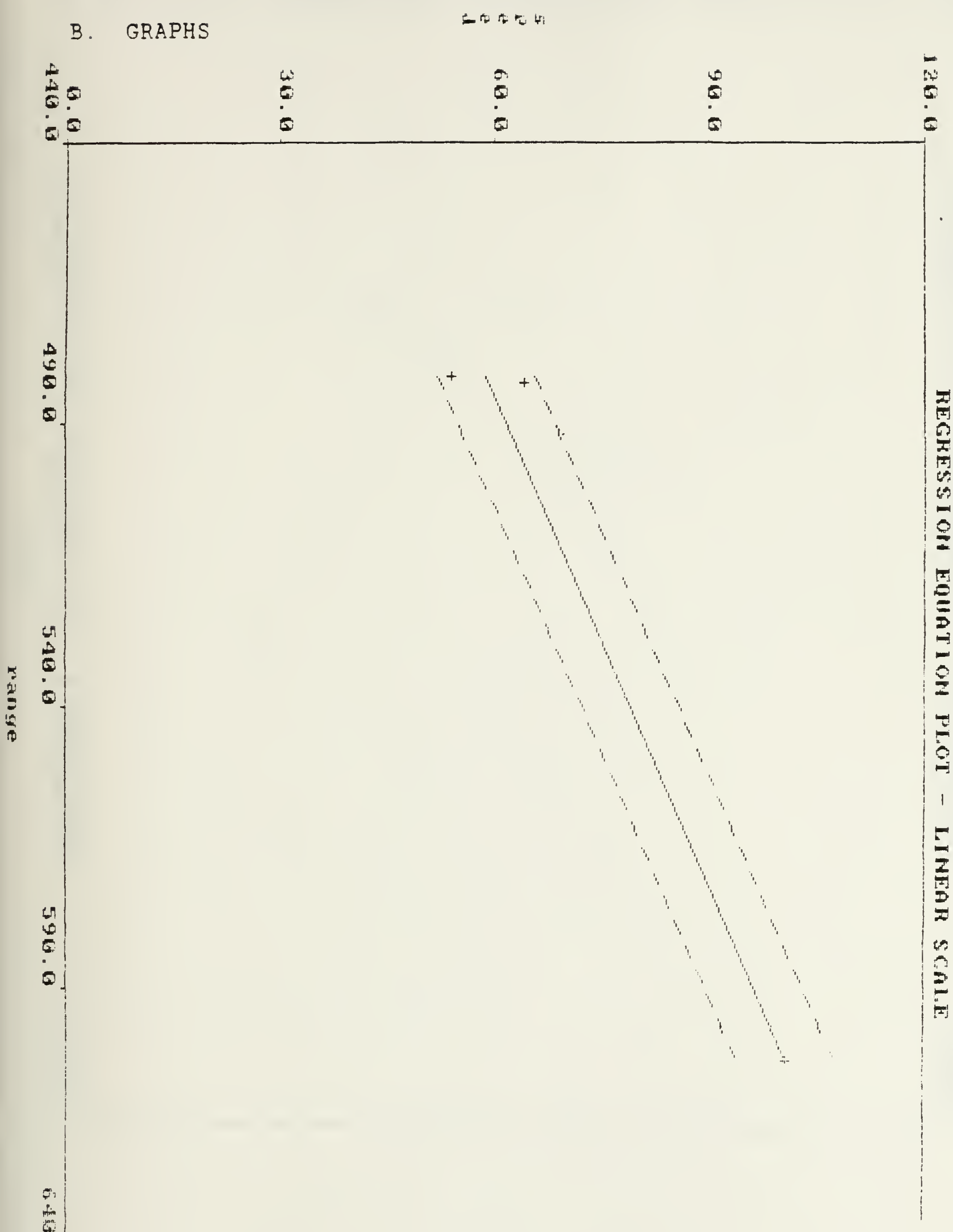
O&S COSTS=-3728.5+10.5RANGE pg.98

R^2=.981   SE=144.6   F-statistic=51   t-ratio=7.15

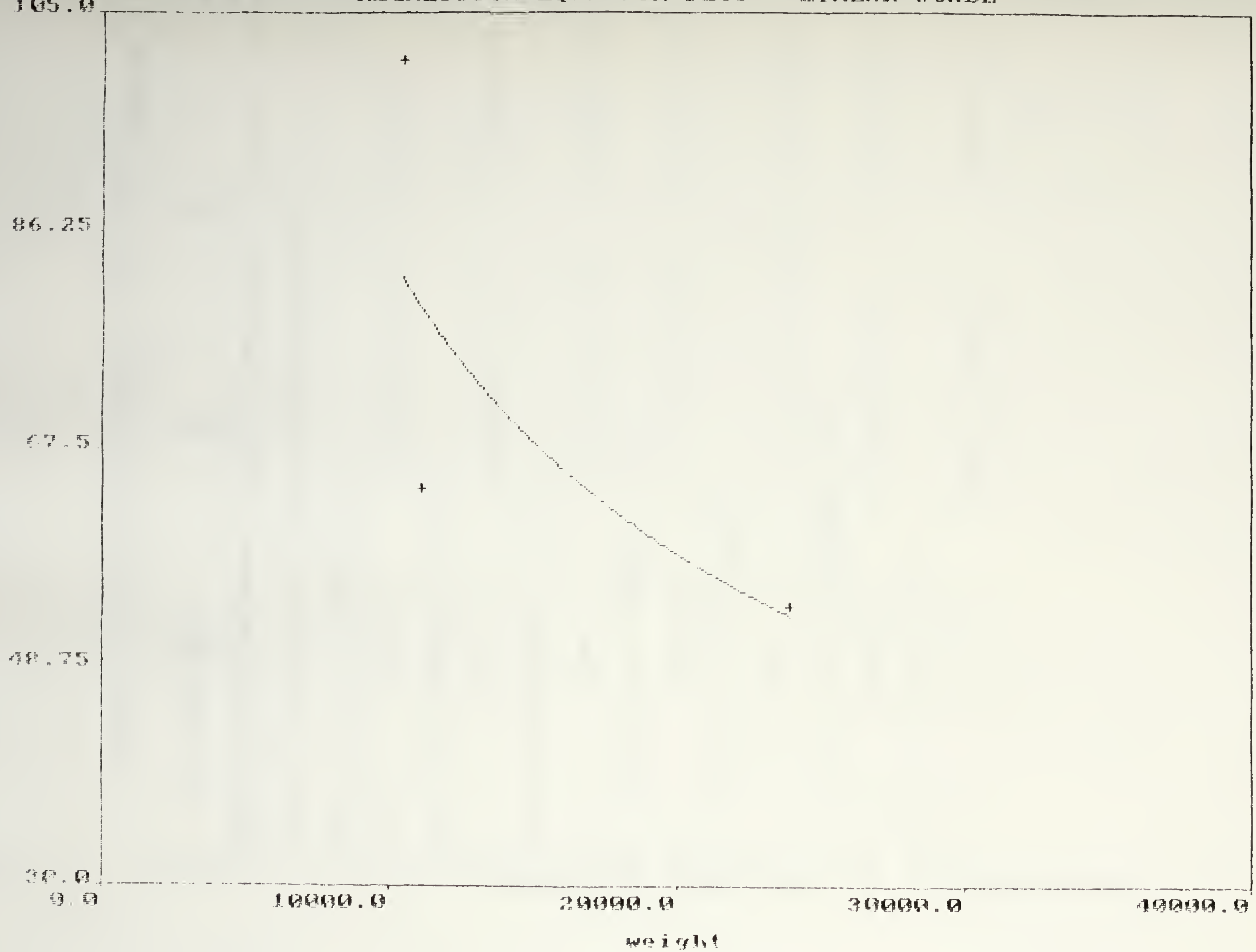
RANGE=e$^{(5.9+.005SPEED)}$ pg.99

R^2=.962   SE=17.3   F-statistic=25.6   t-ratio=5.05

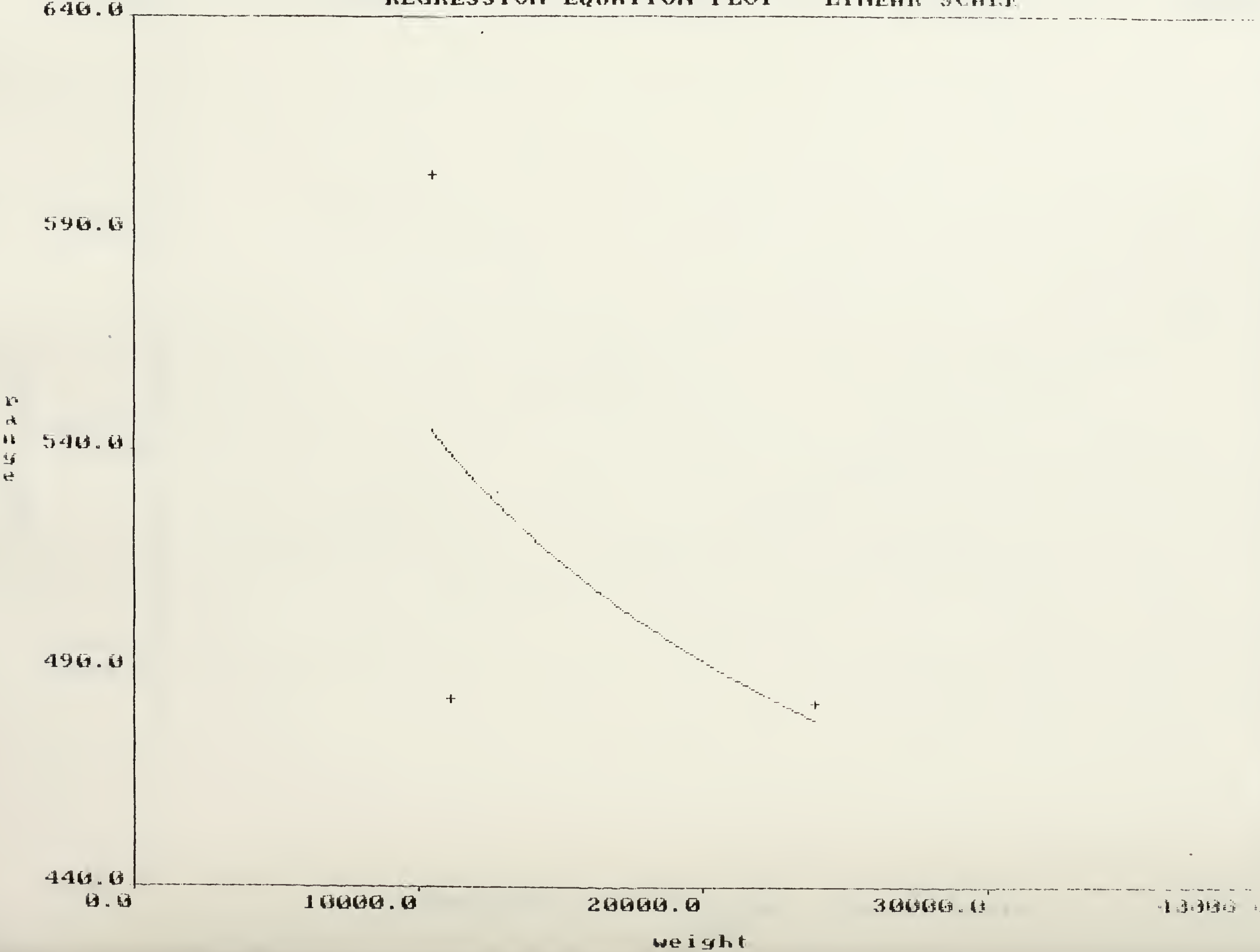
B. GRAPHS

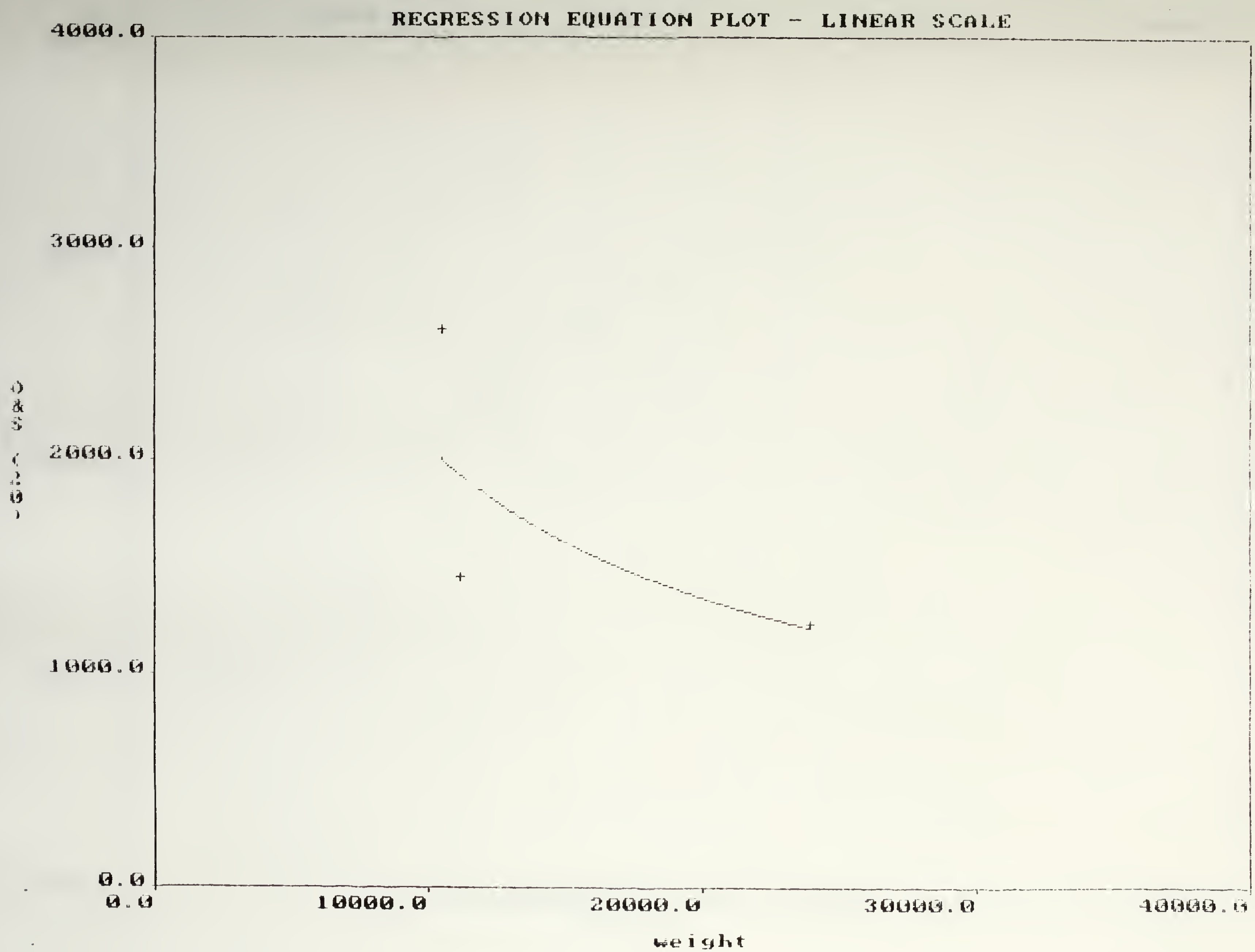

REGRESSION EQUATION PLOT - LINEAR SCALE
speed
0.0
30.0
60.0
90.0
120.0
440.0
490.0
540.0
590.0
640
range

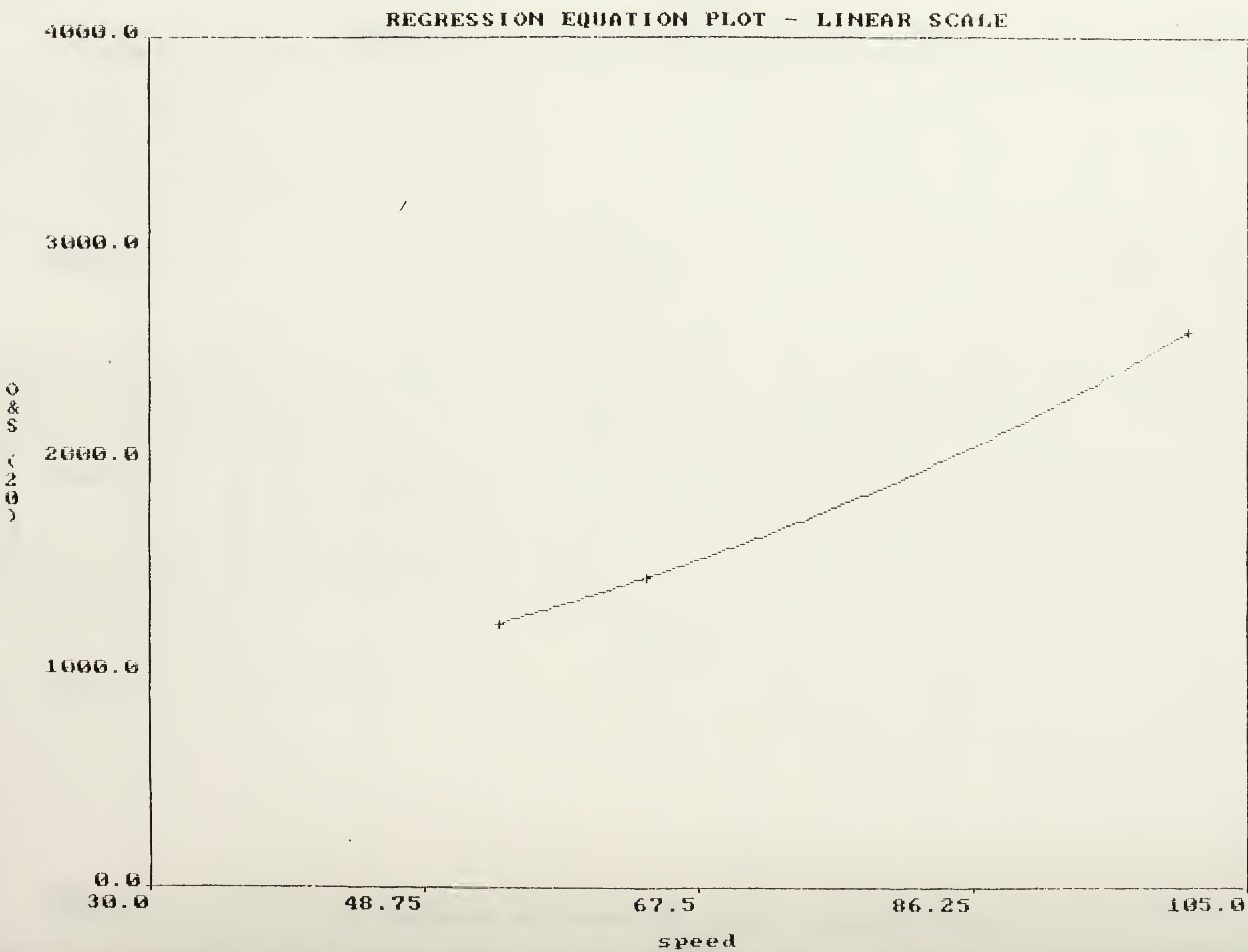
REGRESSION EQUATION PLOT - LINEAR SCALE

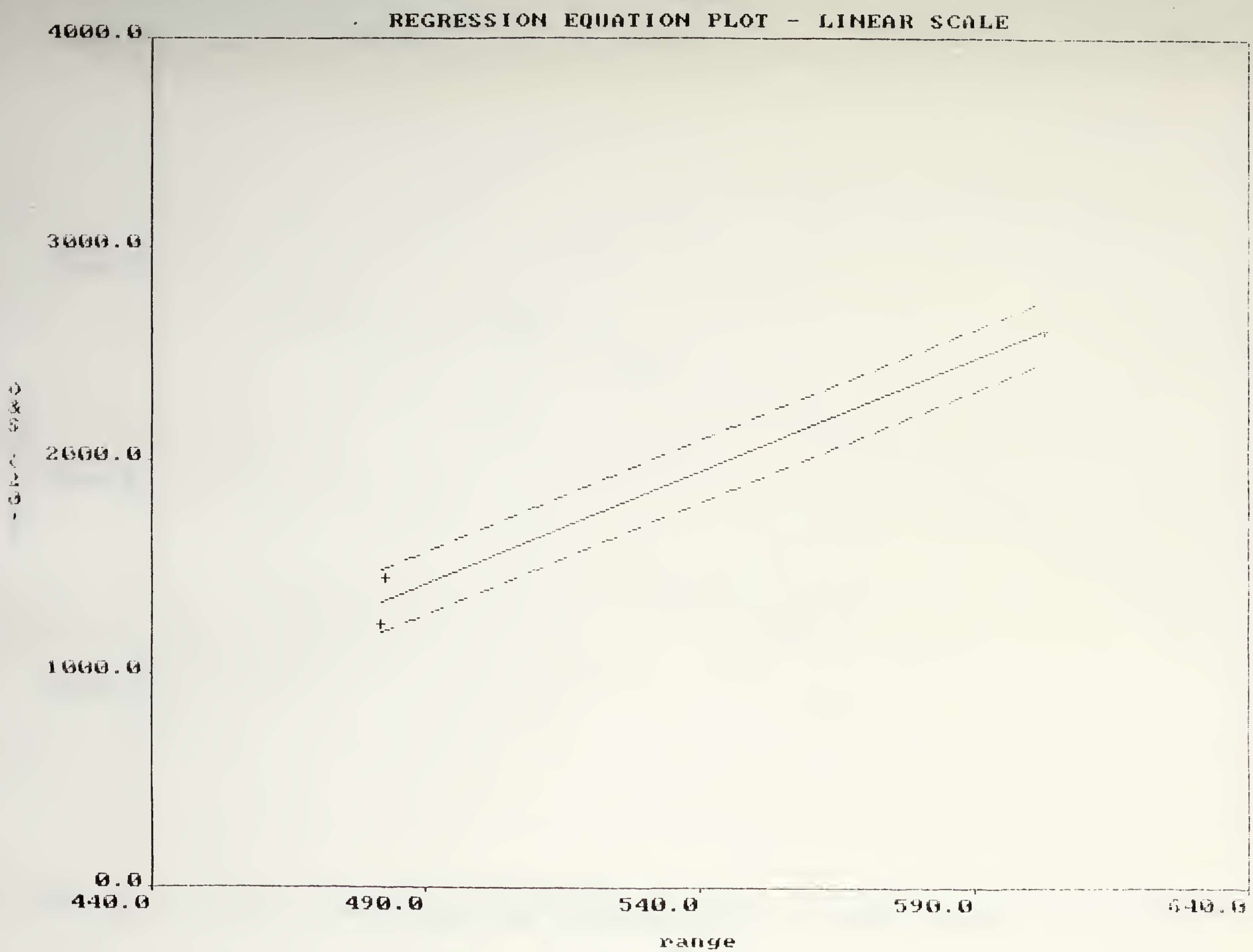


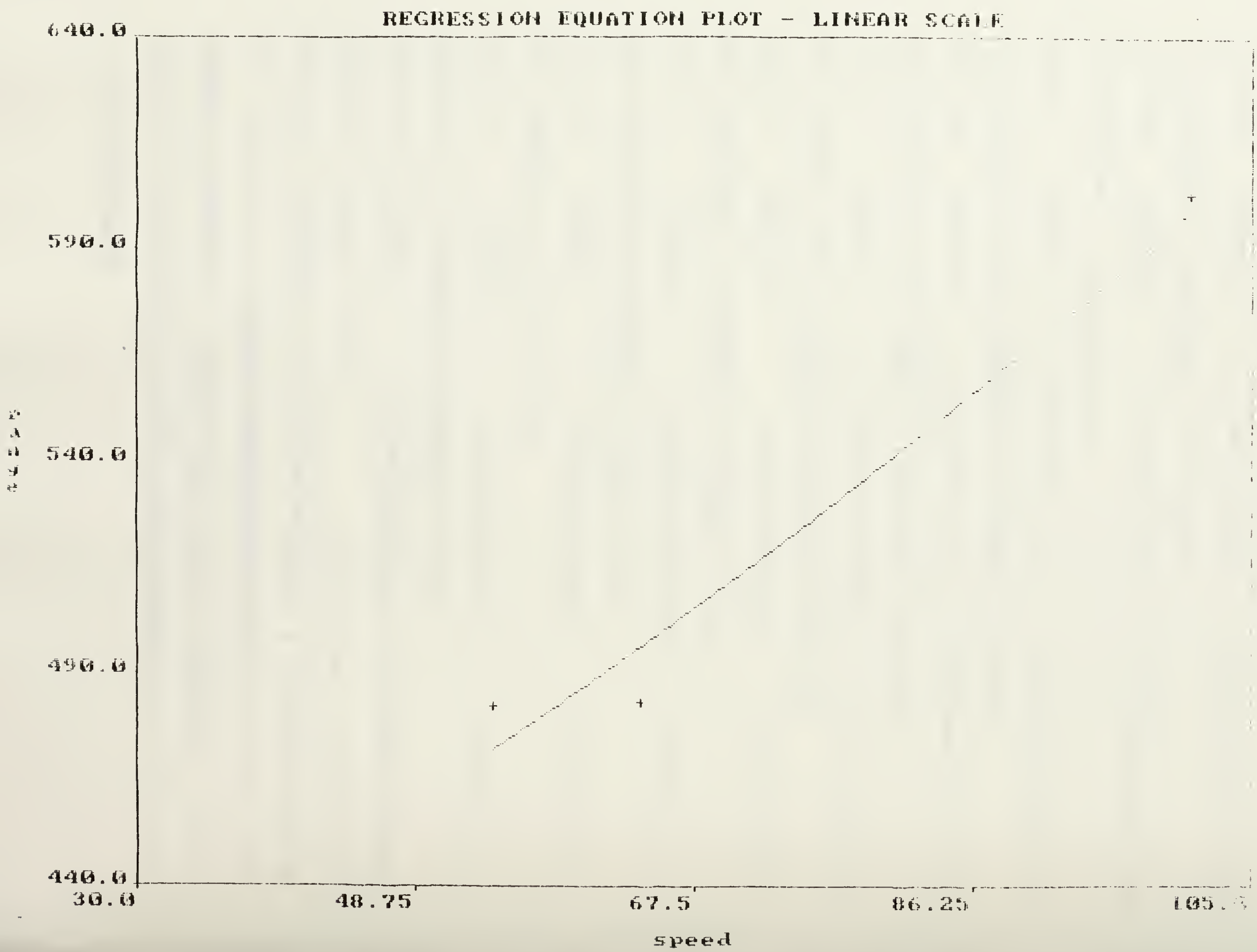
REGRESSION EQUATION PLOT - LINEAR SCALE




REGRESSION EQUATION PLOT - LINEAR SCALE
4000.0
3000.0
2000.0
1000.0
0.0
0.0
10000.0
20000.0
30000.0
40000.0
weight


REGRESSION EQUATION PLOT - LINEAR SCALE
4000.0
3000.0
2000.0
1000.0
0.0
O&S (20)
30.0
48.75
67.5
86.25
105.0
speed


REGRESSION EQUATION PLOT - LINEAR SCALE
4000.0
3000.0
2000.0
1000.0
0.0
440.0
490.0
540.0
590.0
640.0
range


REGRESSION EQUATION PLOT - LINEAR SCALE
640.0
590.0
540.0
490.0
440.0
range
30.0
48.75
67.5
86.25
speed

C. 2ND ITERATION

NUMBER OF OBSERVATIONS:4 (AAV7A1,M113,LAV,LCAC)

NUMBER OF VARIABLES:5 (RANGE,SPEED,WEIGHT,CREW,COST)

O&S COSTS=468.7-5.15RANGE+.014RANGE^2 pg.102

R^2=.99 SE=145.8 F-statistic=79.3 t-ratio=-1.5

RANGE=$e^{(6.3-.000007WEIGHT)}$ pg.103

R^2=.971 SE=59.7 F-statistic=66 t-ratio=-8.1

RANGE=3321.6-79.9SPEED+.524SPEED^2 pg.104

R^2=.705 SE=167 F-statistic=1.2 t-ratio=-1.4

O&S COSTS=$e^{(7.9-.000033WEIGHT)}$ pg.105

R^2=.992 SE=567 F-statistic=246 t-ratio=-15.7

O&S COSTS=15040-396SPEED+2.7SPEED^2 pg.106

R^2=.76 SE=909.8 F-statistic=1.55 t-ratio=-1.3

O&S COSTS=468.7-5.15RANGE+.014RANGE^2 pg.107

R^2=.99 SE=145.8 F-statistic=79.3 t-ratio=-1.58

O&S COSTS=-3955+10.6RANGE+.011WEIGHT pg.107-108

R^2=.98 SE=254 F-statistic=25.6 t-ratio=3.6R/1.7W

O&S COSTS=-64.9+27.3SPEED-.011WEIGHT pg.109-110

R^2=.994 SE=146.7 F-statistic=78.3 t-ratio=6.5S/-10.5W

O&S COSTS=-2097.4+5.25RANGE+15.3SPEED pg.111-112

R^2=1 SE=41 F-statistic=e+3 t-ratio=37.6R/12.5S

O&S COSTS=$e^{(7.3+.009SPEED-.000032WEIGHT)}$

R^2=.997 SE=369 F-statistic=24 t-ratio=42.5S/6.21W

O&S COSTS=$e^{(6.7+.5CREW-.00004WEIGHT)}$ pg.113-114

R^2=.999 SE=275 F-statistic=433 t-ratio=2.4C/-12.5W

$\text{O\&S COSTS}=3.08e\text{-}9\,\text{CREW}^{-.815}\text{RANGE}^{4.45}$

$R^2=.998$ SE=321 F-statistic=297 t-ratio=-1.7C/13R

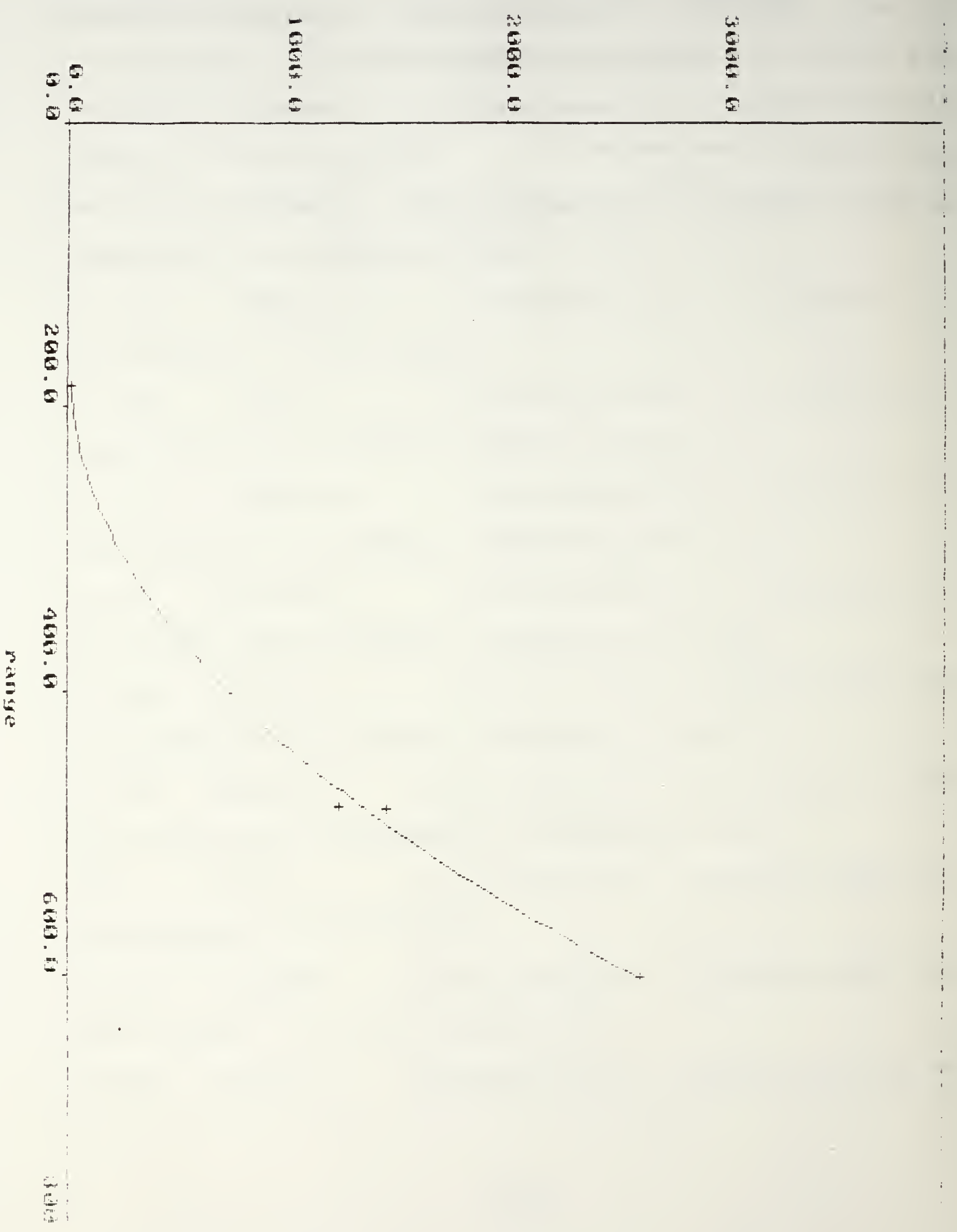
$\text{O\&S COSTS}=939.8-657.6\,\text{CREW}+34.4\,\text{SPEED}$

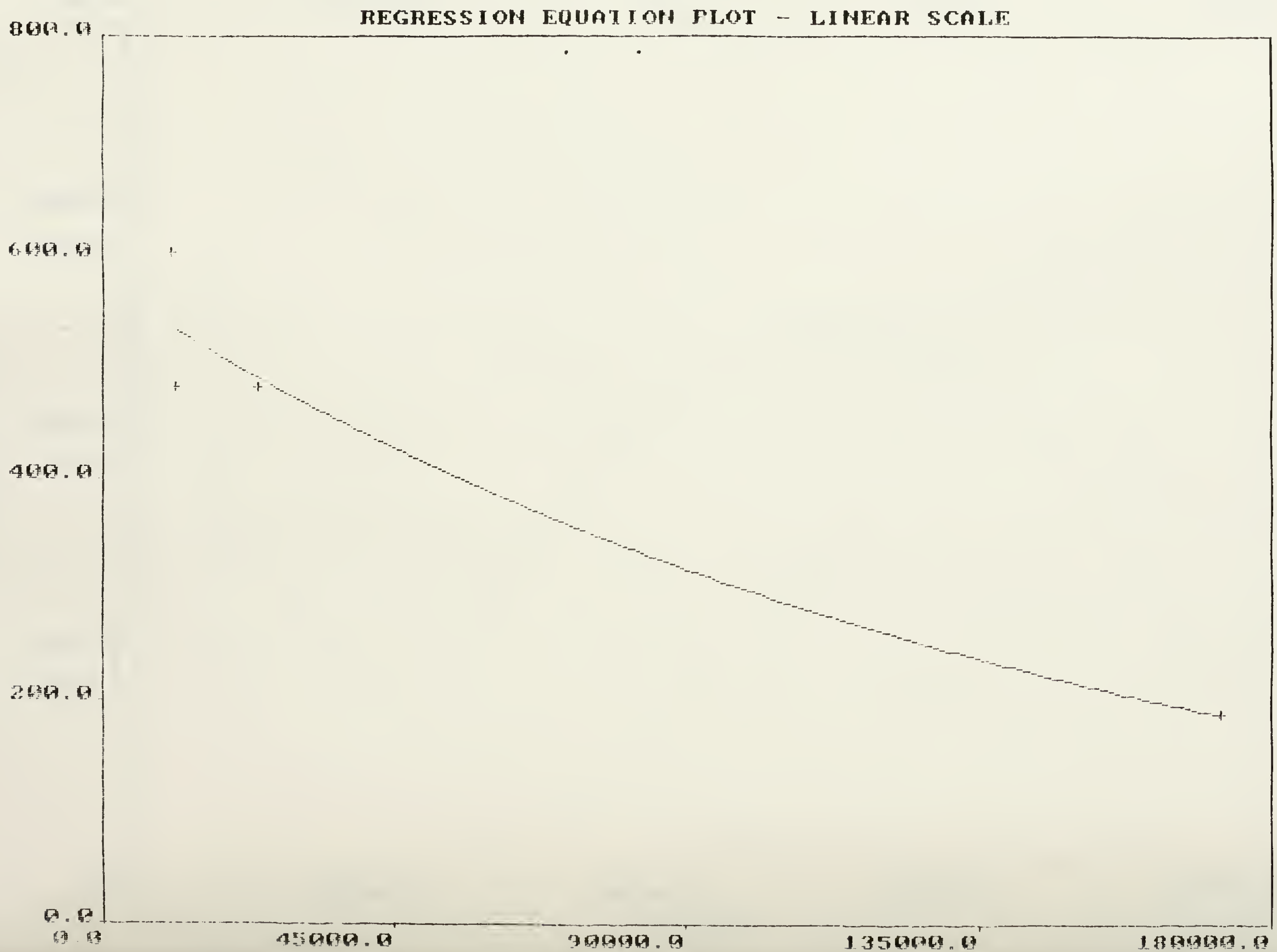
$R^2=.89$ SE=610 F-statistic=4.06 t-ratio=-2.3C/1.9S

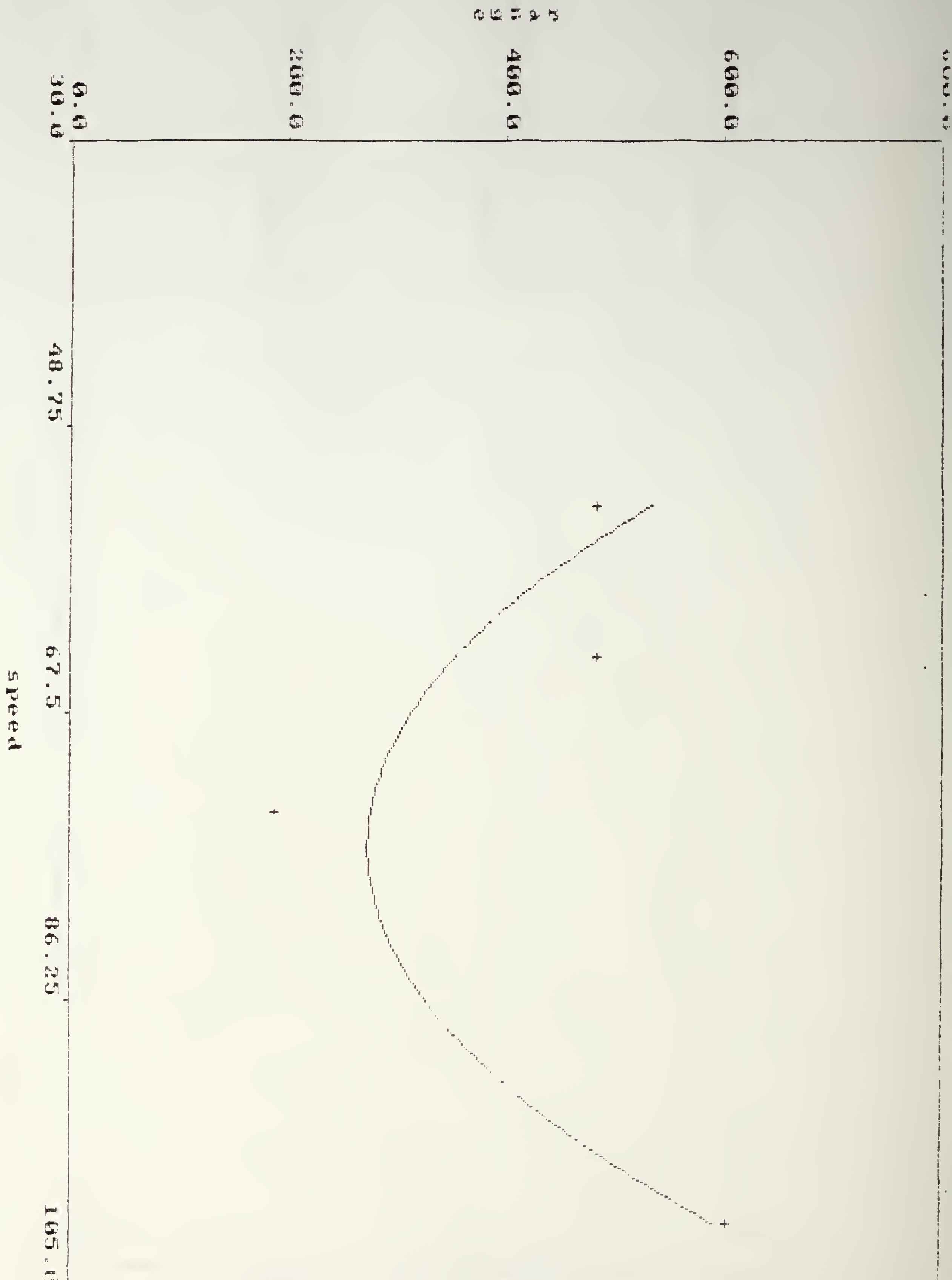
$\text{O\&S COSTS}=e^{(6.7+.5\text{CREW}-.00004\text{WEIGHT})}$

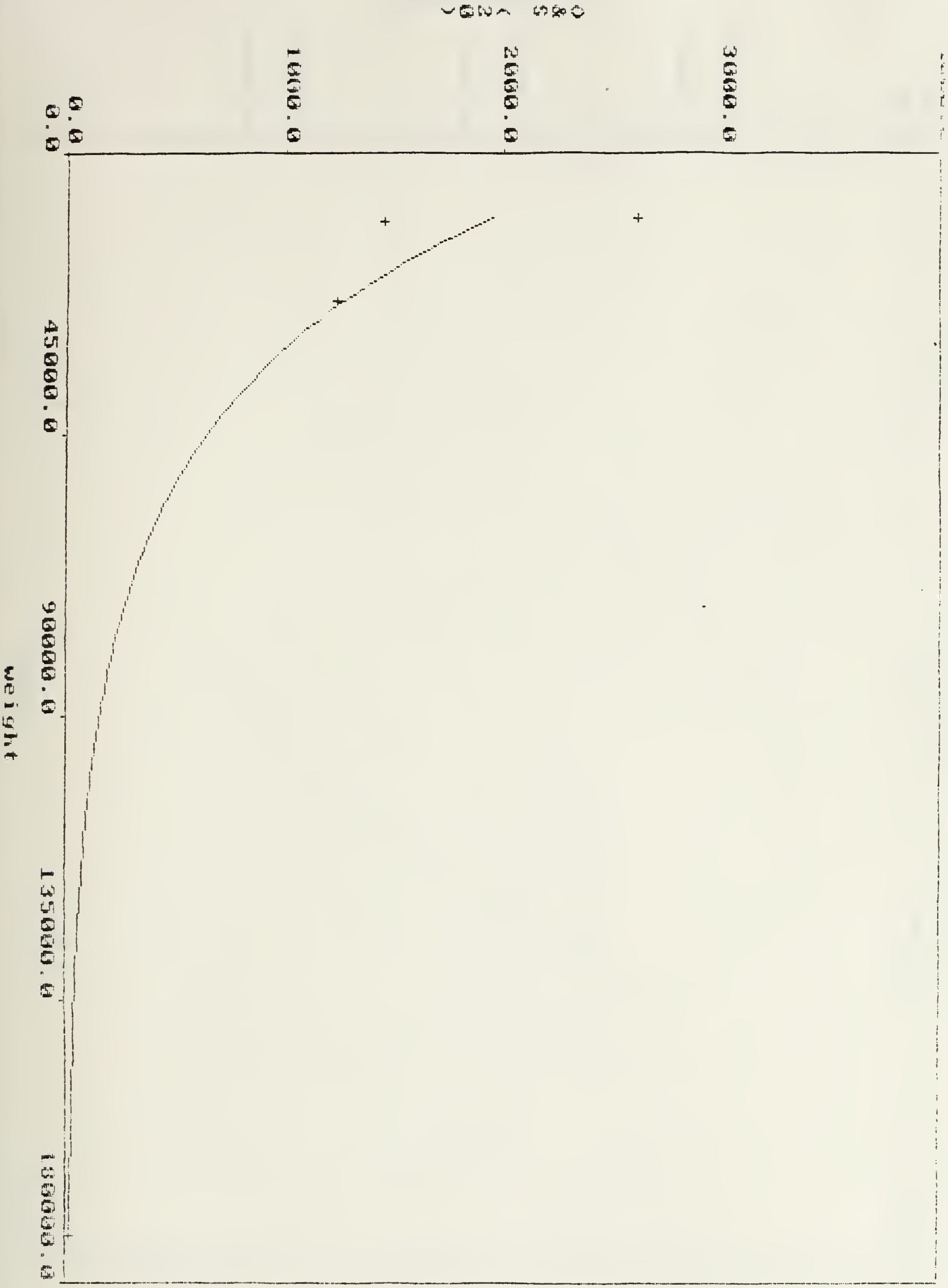
$R^2=.999$ SE=275.8 F-statistic=433 t-ratio=2.5C/-12.5W

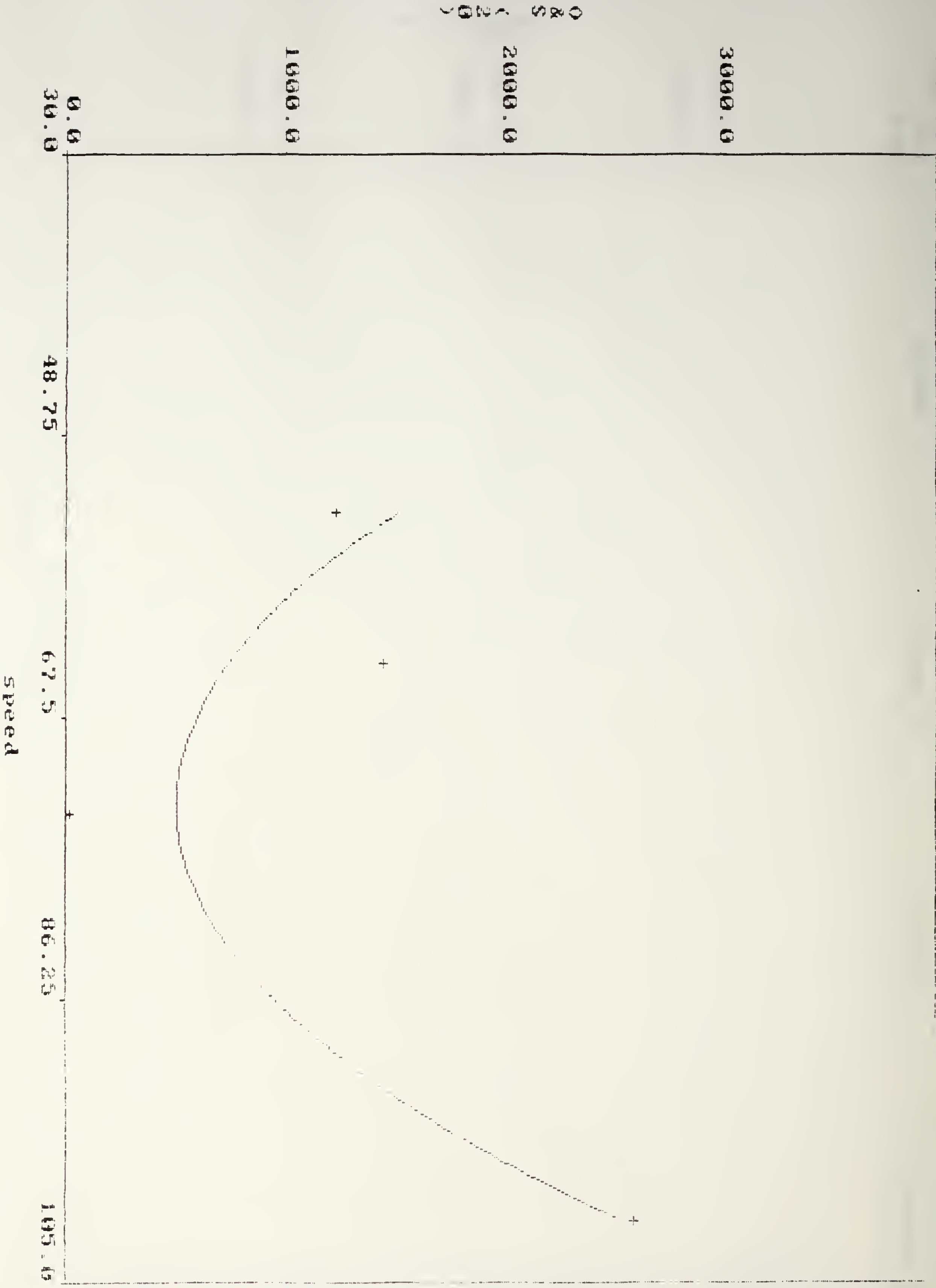
D. GRAPHS



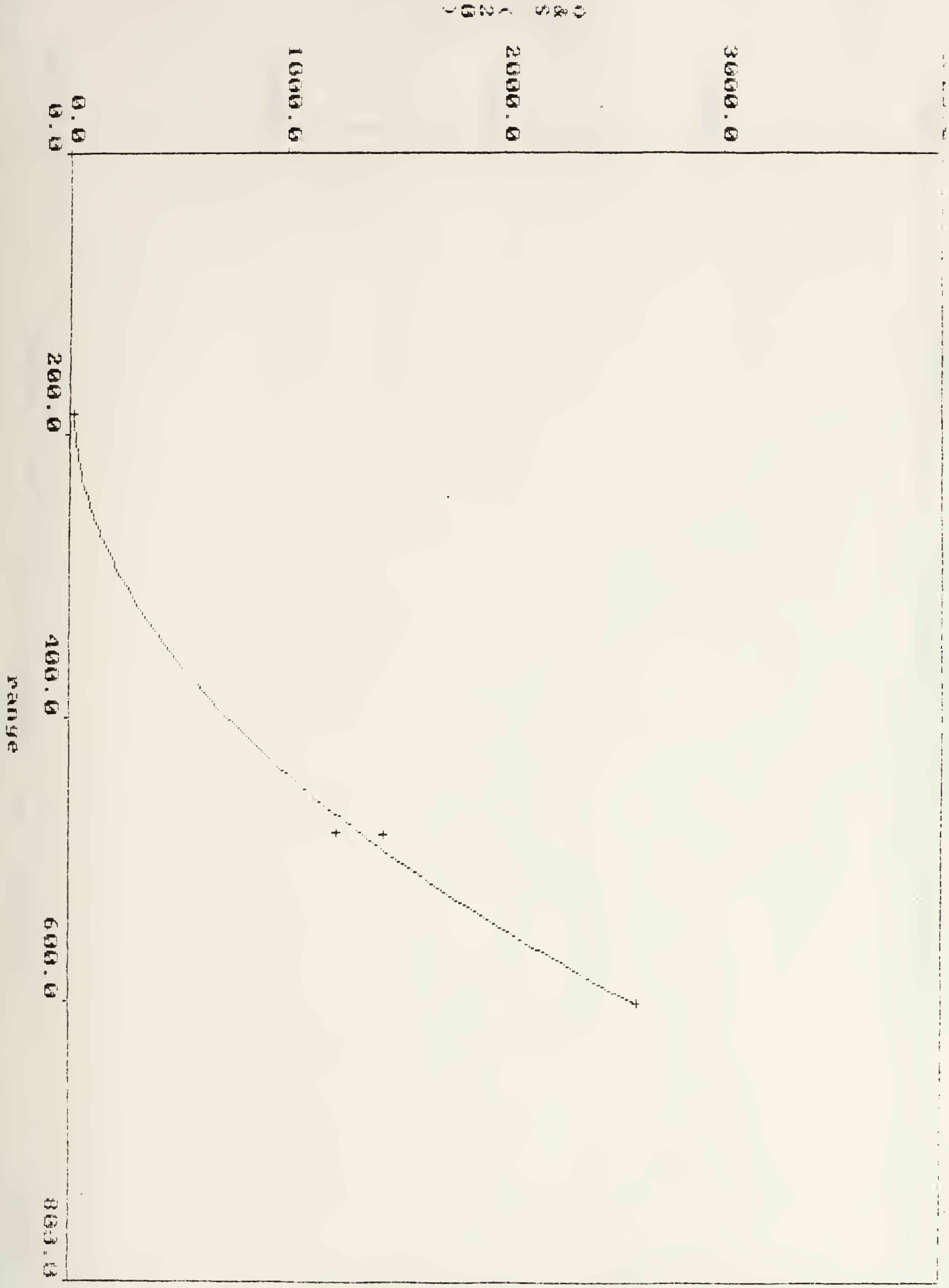

REGRESSION EQUATION PLOT - LINEAR SCALE
800.0
600.0
400.0
200.0
0.0
0.0
45000.0
90000.0
135000.0
180000.0


range
0.0
200.0
400.0
600.0
30.0
48.75
67.5
86.25
105.0
speed

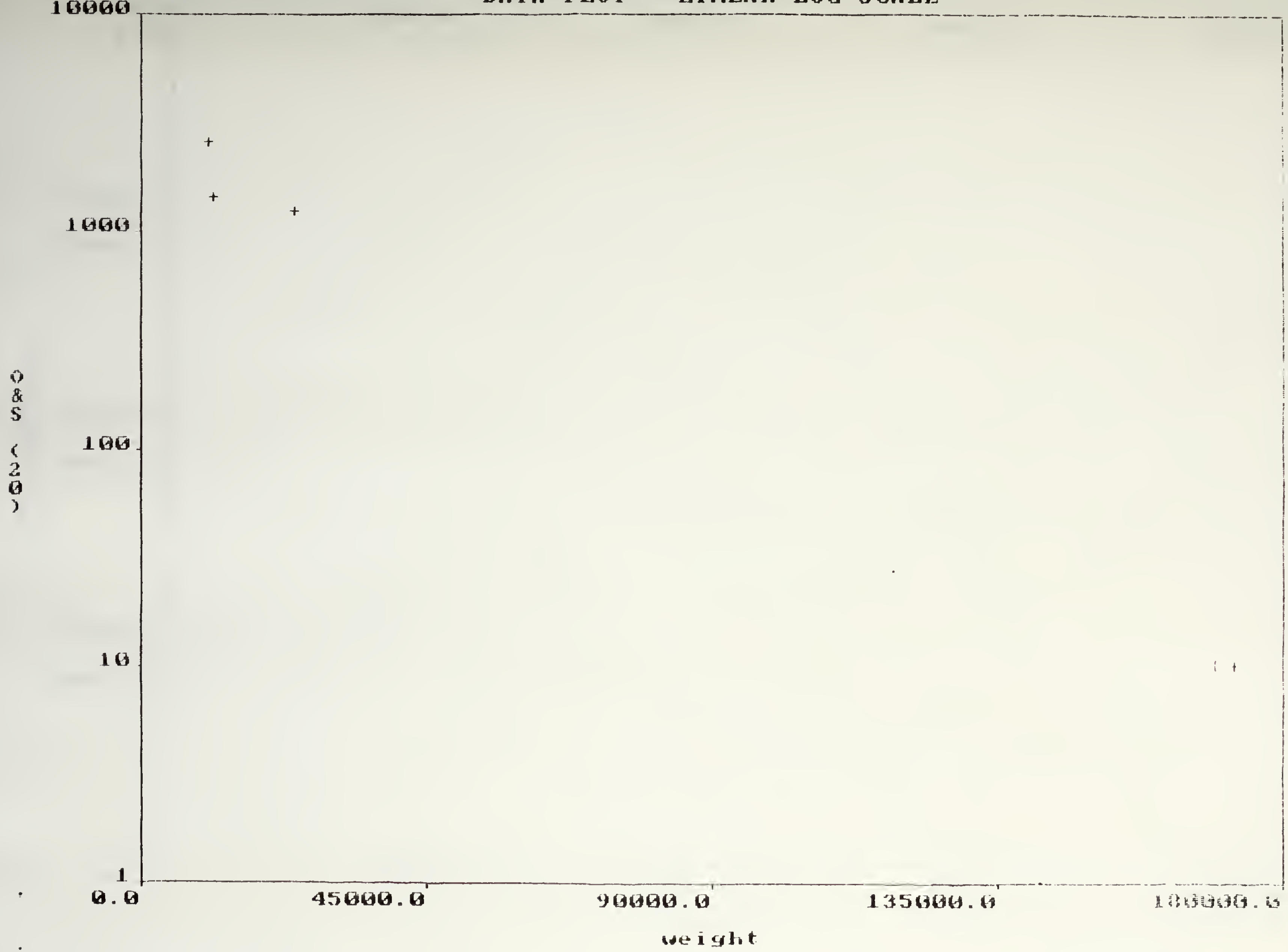

0.0
1000.0
2000.0
3000.0
0.0
45000.0
90000.0
135000.0
180000.0
weight

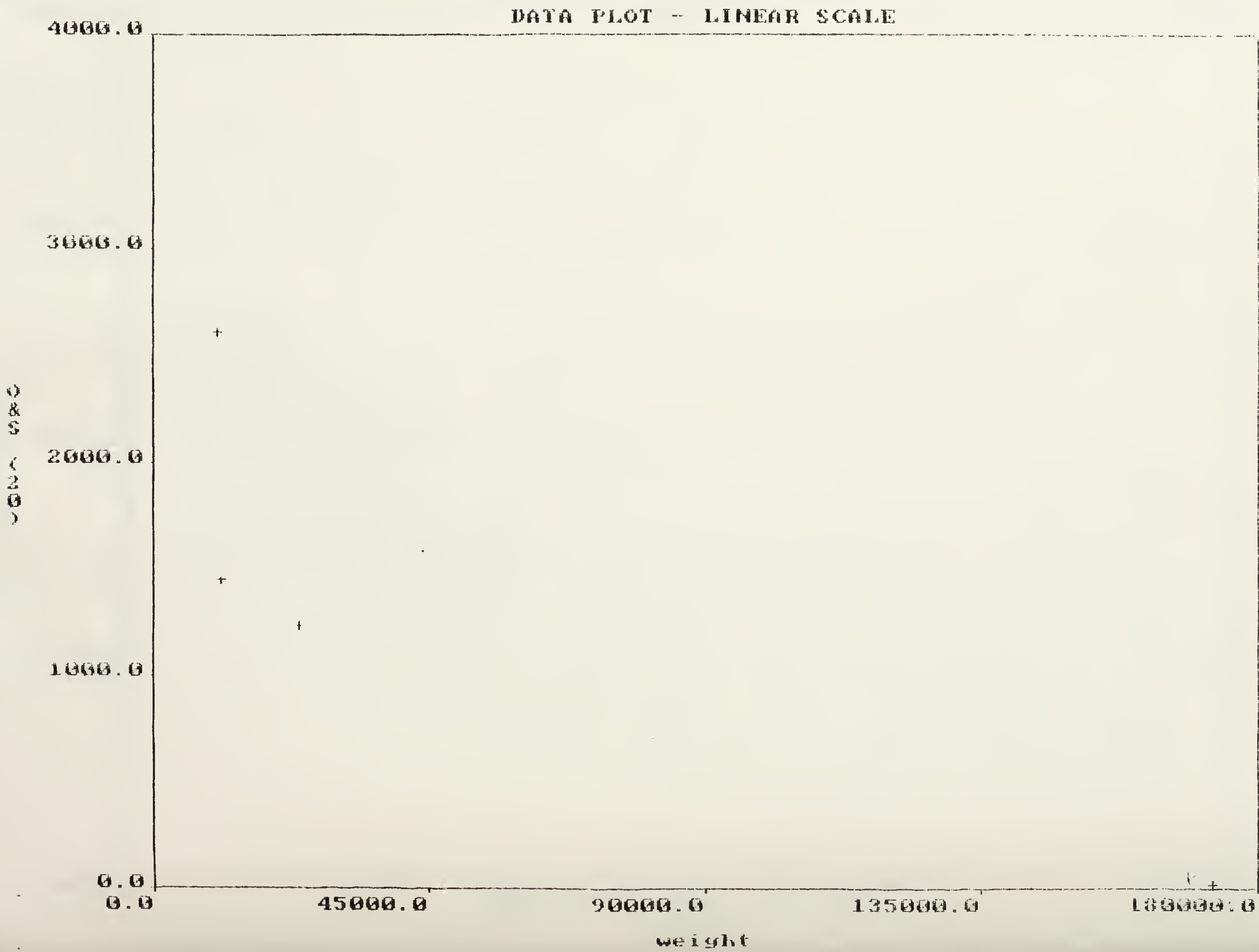


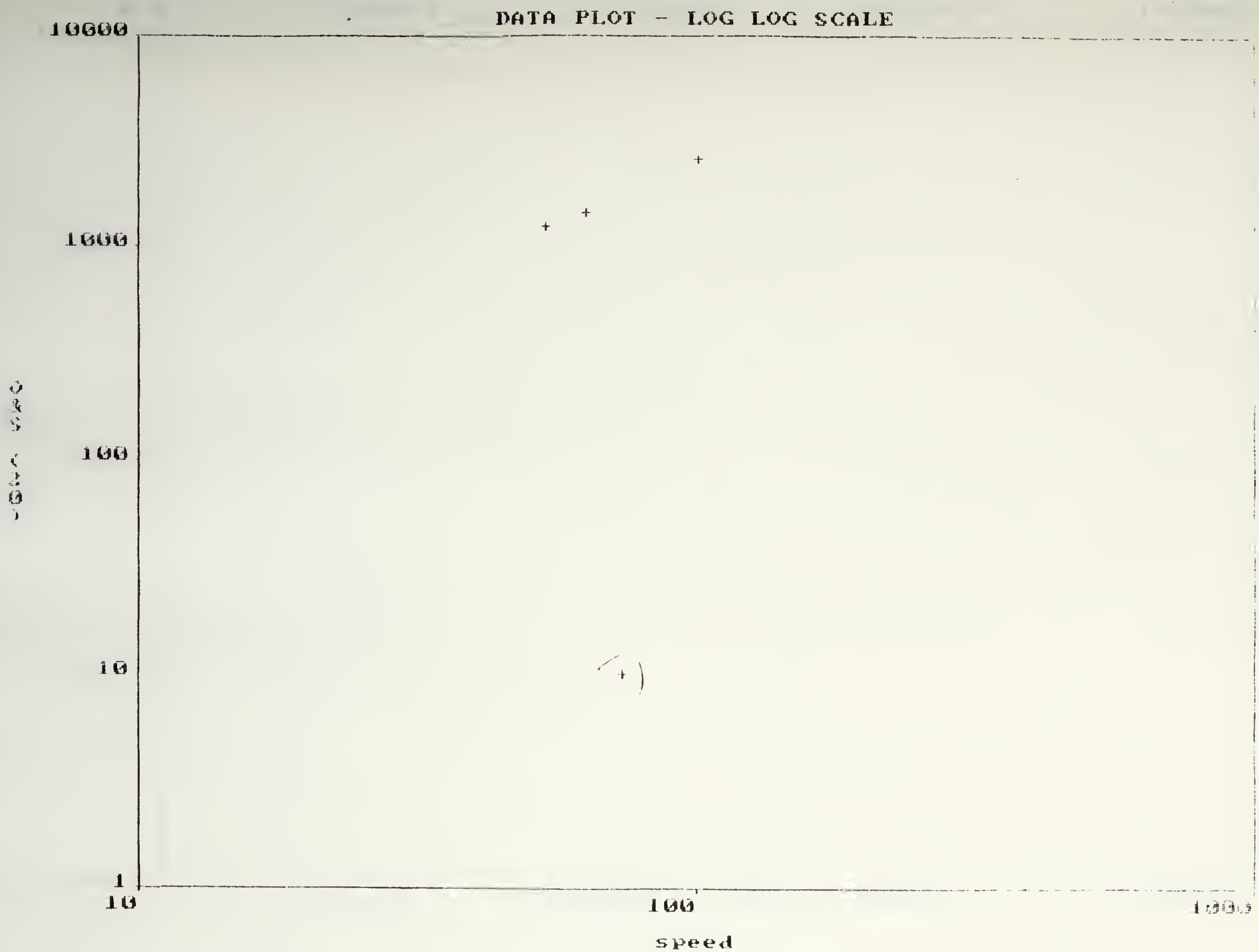
0.0
1000.0
2000.0
3000.0
30.0
48.75
67.5
86.25
105.0
speed


0.0
1000.0
2000.0
3000.0
0.0
200.0
400.0
600.0
Range

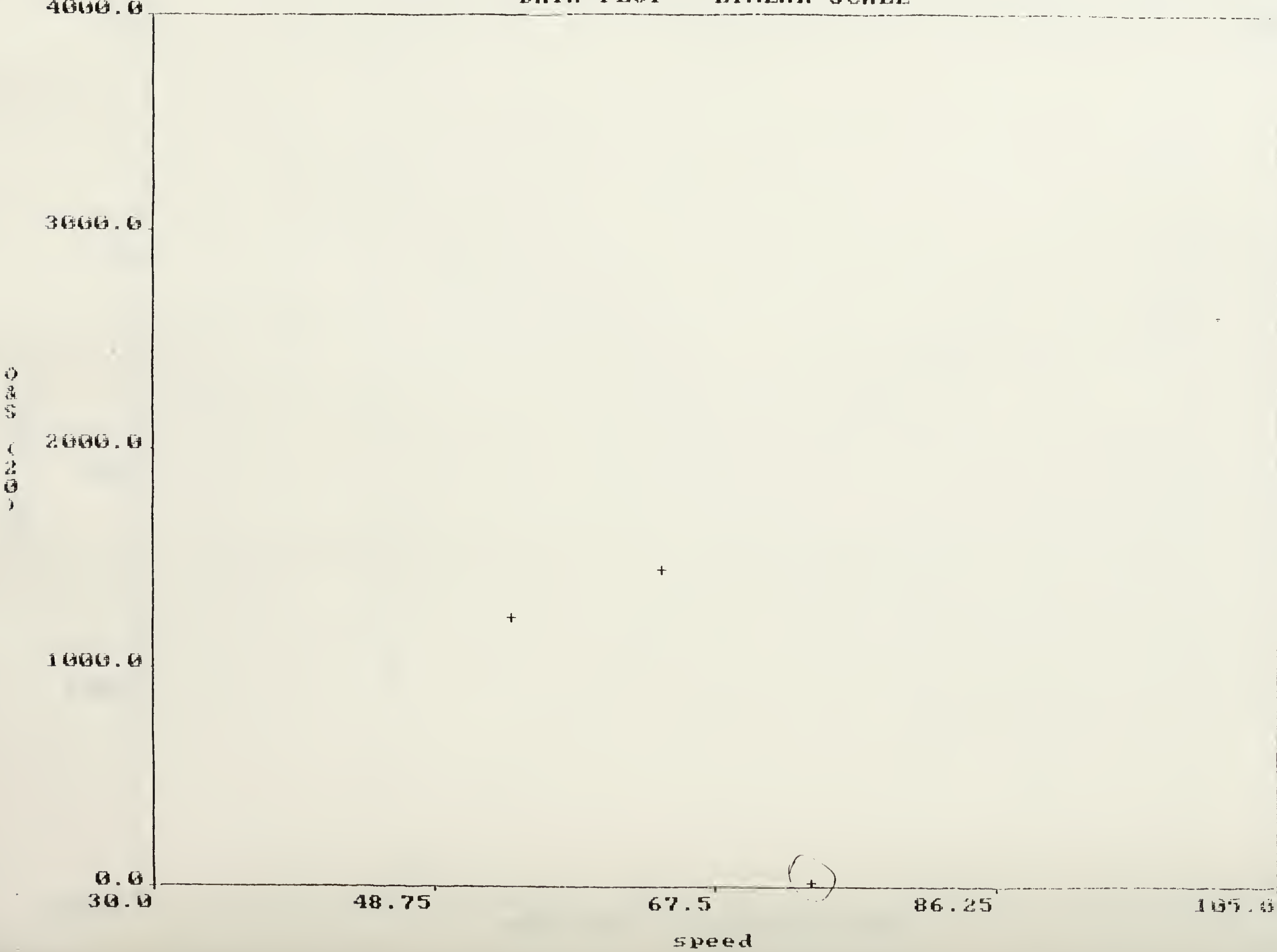
DATA PLOT - LINEAR LOG SCALE

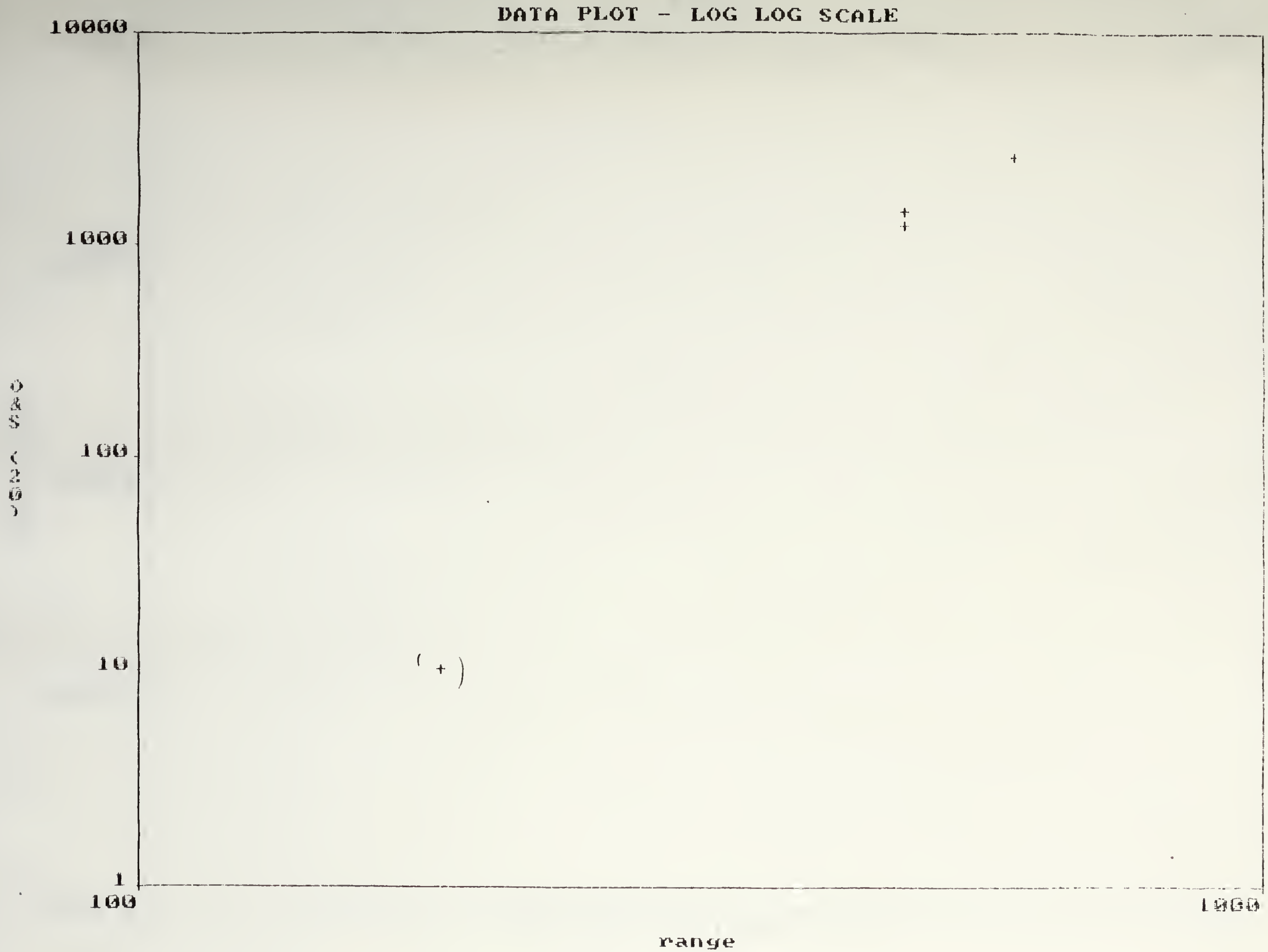


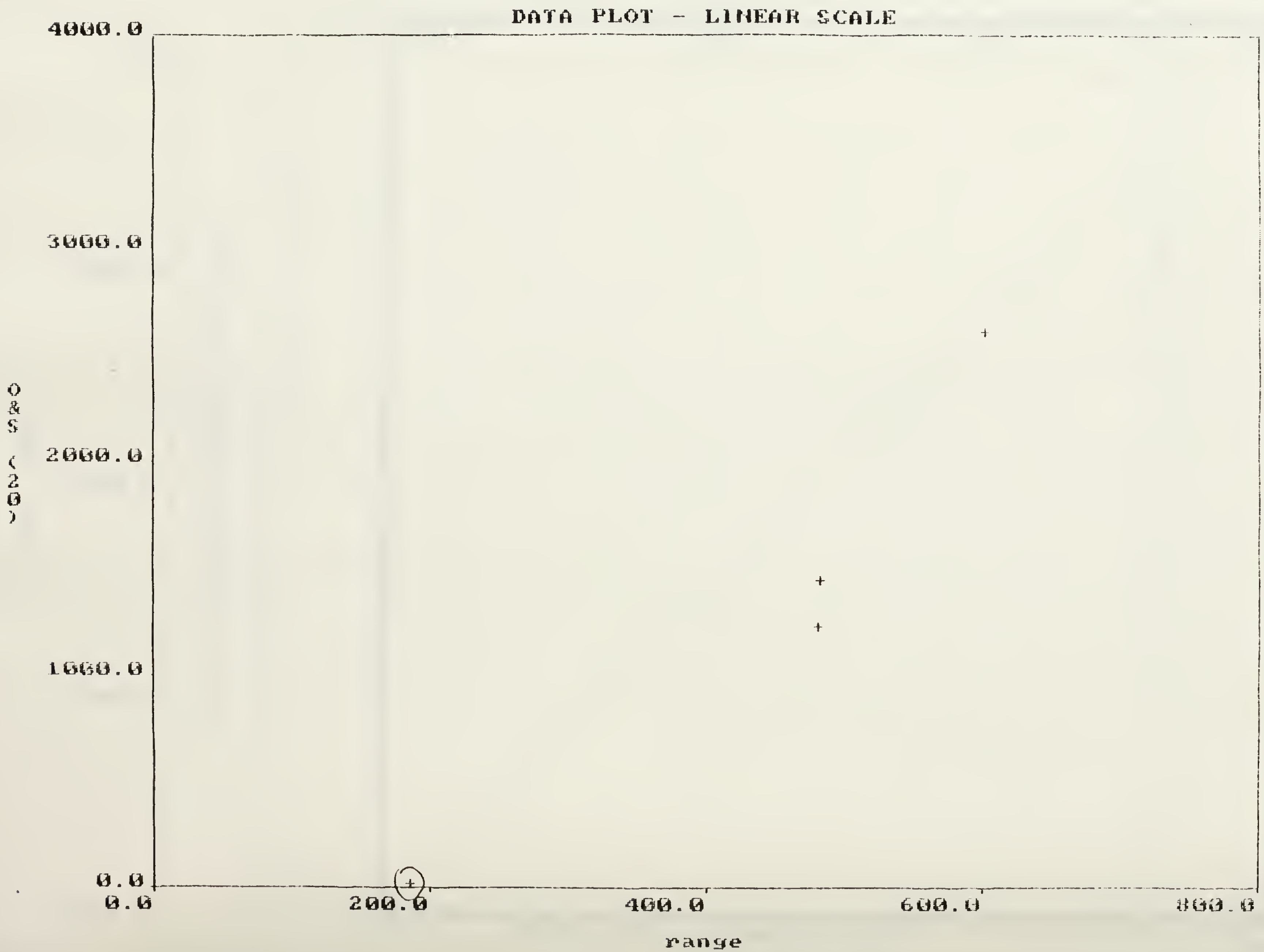

DATA PLOT - LINEAR SCALE
4000.0
3000.0
2000.0
1000.0
0.0
O&S (20)
0.0
45000.0
90000.0
135000.0
180000.0
weight

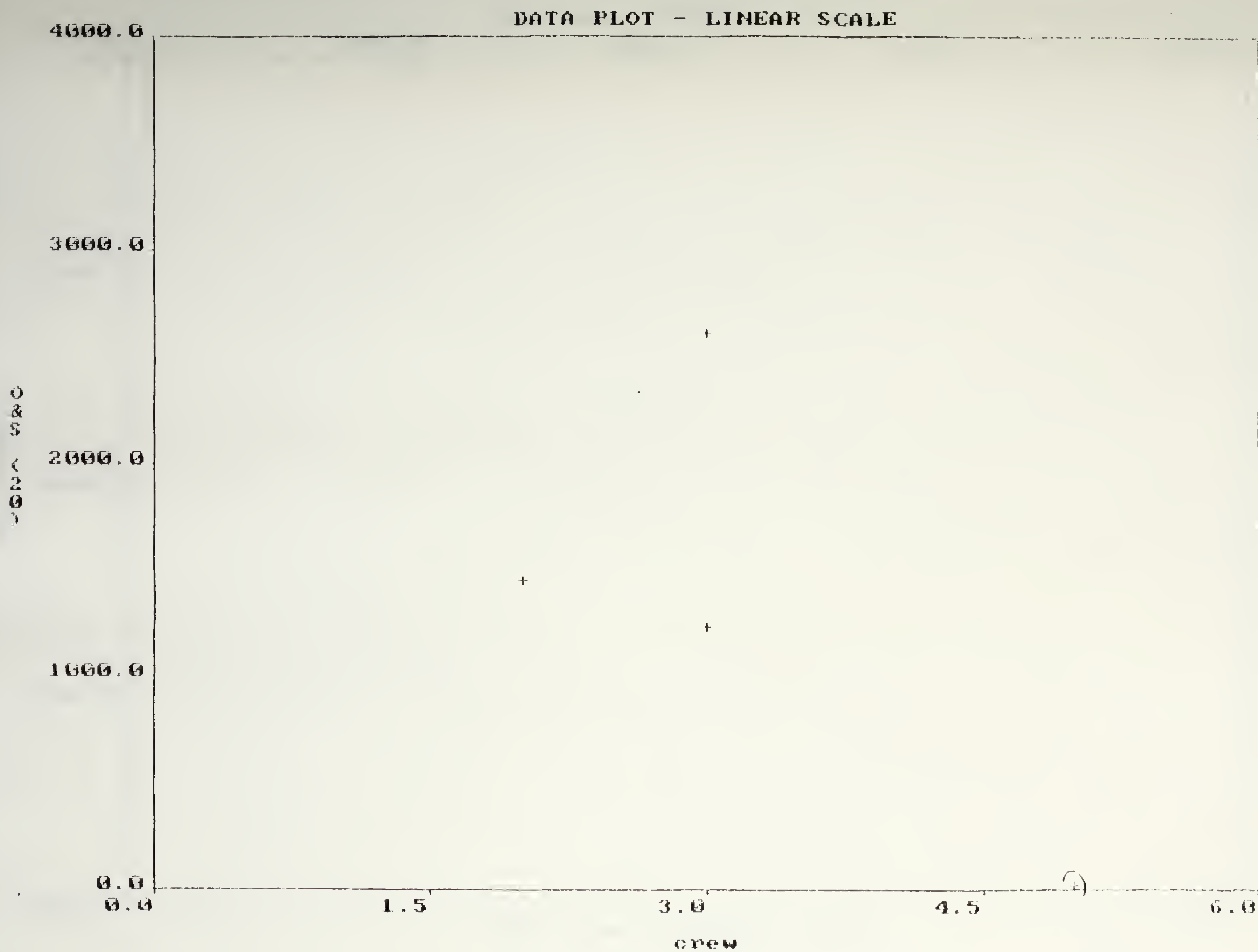

DATA PLOT - LOG LOG SCALE
10000
1000
100
10
1
10
100
1000
speed
OBS (20)

DATA PLOT - LINEAR SCALE

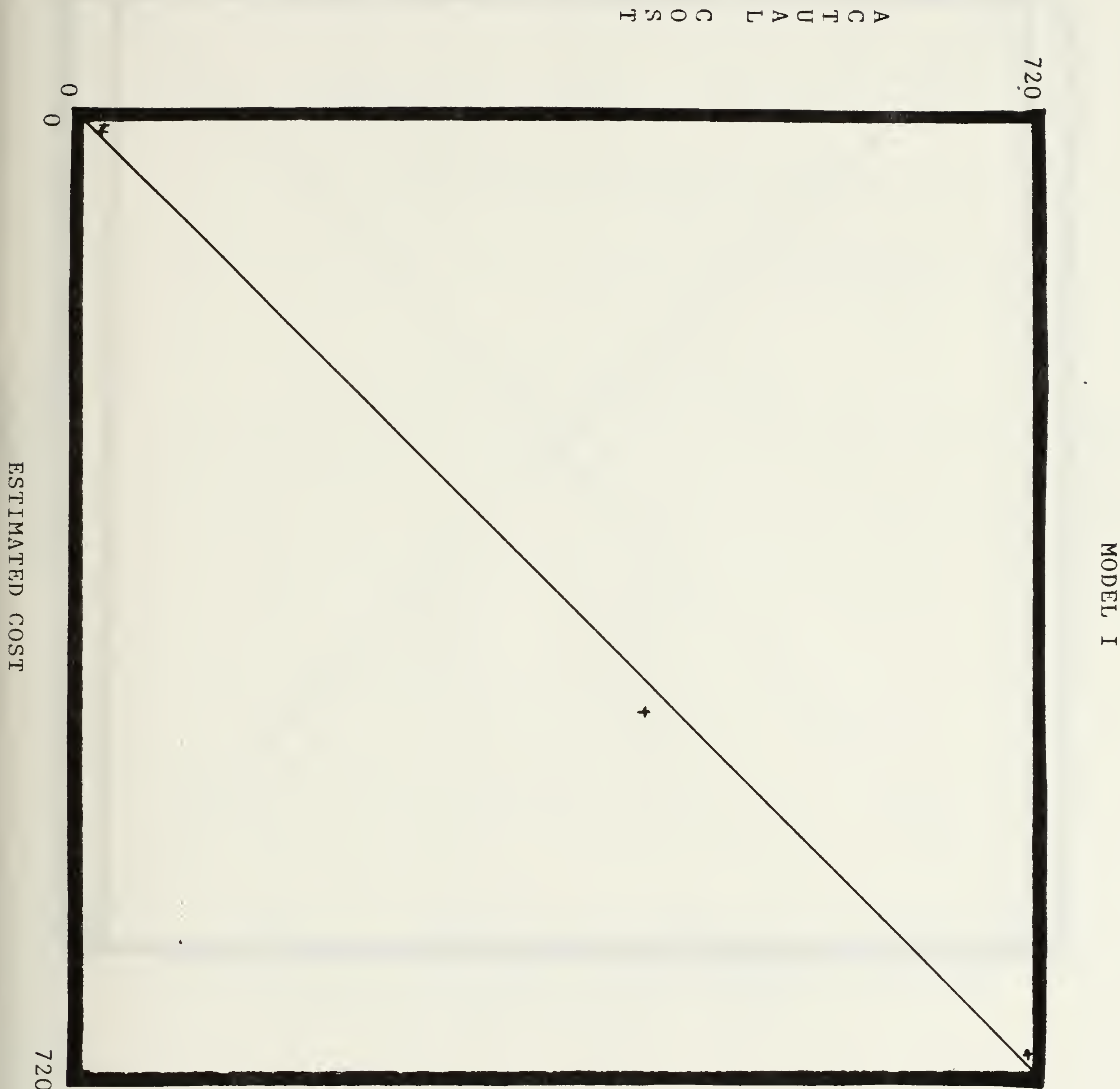



DATA PLOT - LOG LOG SCALE
O&S (20)
10000
1000
100
10
1
100
1000
range

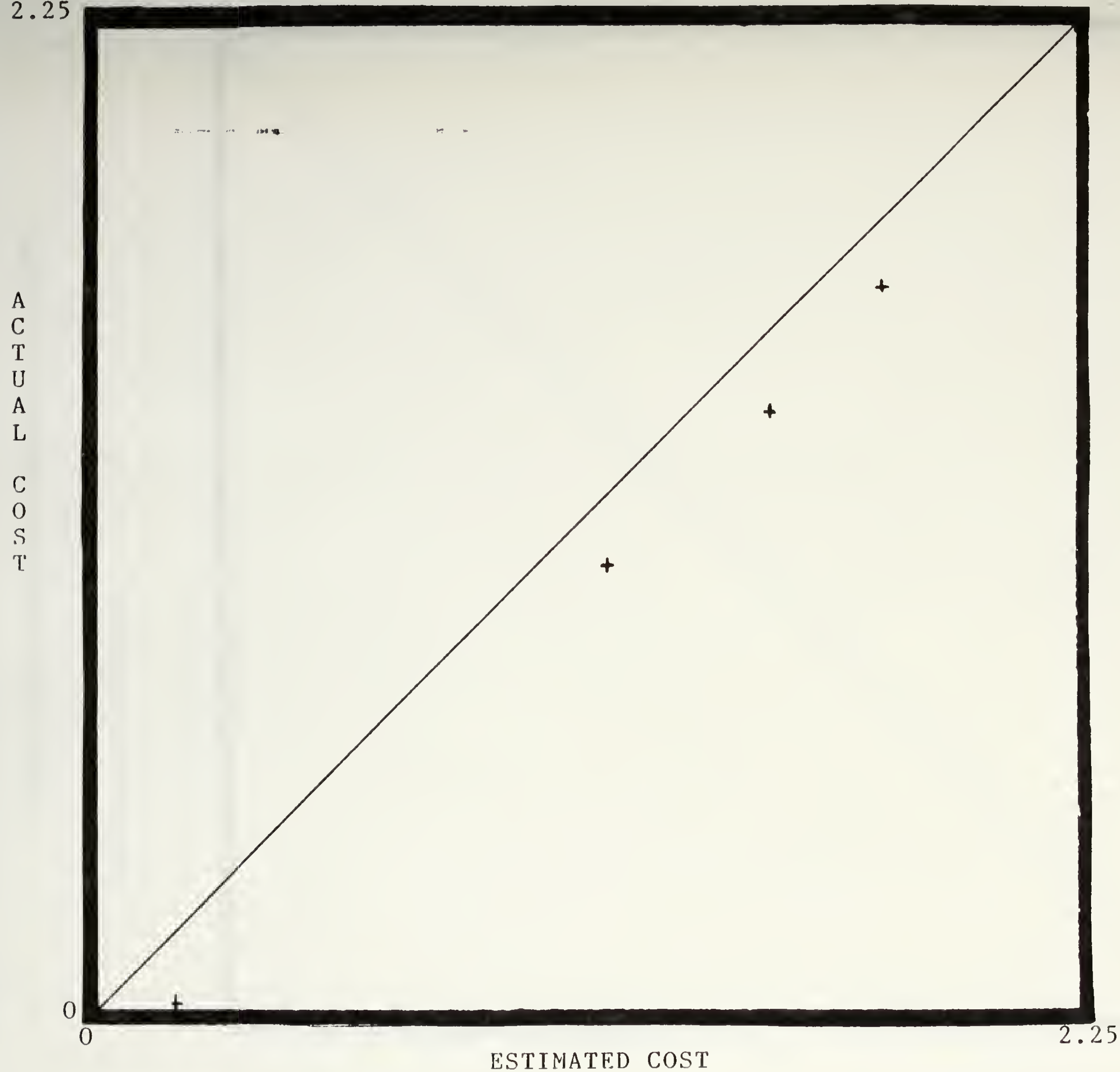

DATA PLOT - LINEAR SCALE
4000.0
3000.0
2000.0
1000.0
0.0
O&S (20)
0.0
200.0
400.0
600.0
800.0
range


DATA PLOT - LINEAR SCALE
4000.0
3000.0
2000.0
1000.0
0.0
O&S (20)
0.0
1.5
3.0
4.5
6.0
crew

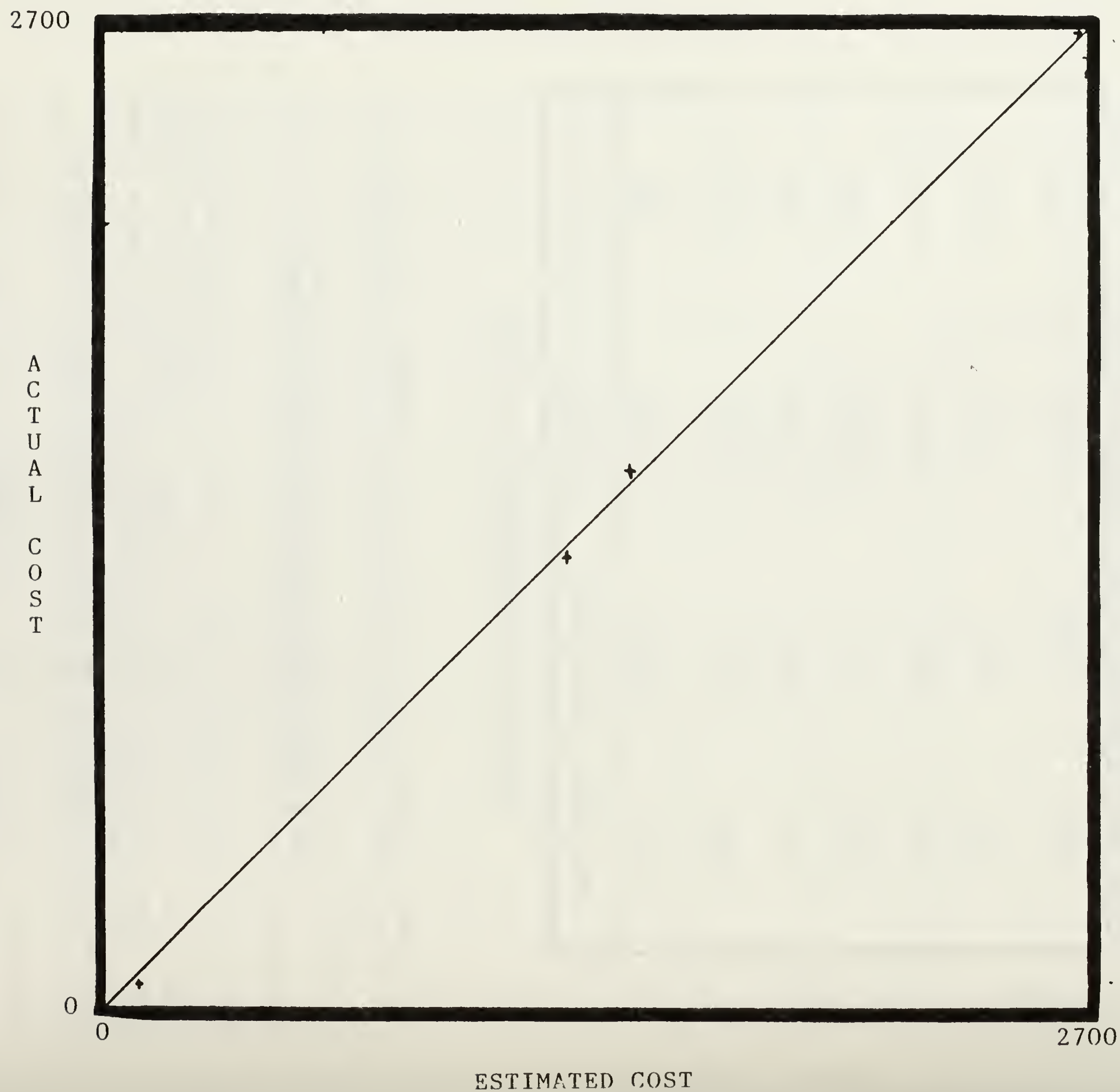
APPENDIX E-RESIDUAL SCATTER DATA PLOTS



MODEL II



MODEL III



APPENDIX F-PROCUREMENT COST DERIVATION

Unlike the traditional method of obtaining procurement cost by deriving theoretical first unit cost, the following method was employed:

Weapon System Cost/Quantity = Unit Cost

Utilizing this equation the following table was derived:

TABLE 15: PROCUREMENT UNIT COSTS

Vehicle	Weapon $	Quantity	Unit Cost
BFV	8270.5	6724	1.23
AAV7A1	297.1	333	.892
M1A1	18457.3	7994	2.3
LCAC	1023.8	42	24.4
M113A1	475.5	5086	.093
LAV-25	549.1	758	.724
M60A3	2488.4	4207	.591

Note: (1) All Dollar amounts are in Millions. (2) Source for data was U. S. Weapon Systems Costs, 1991 by DSA.

The reasoning in using average unit cost vice first unit cost was that the sample population represented such a diverse group with different rate of production and significantly different quantities produced. In this author's opinion the dual role requirement of the AAAV to conduct over the horizon amphibious operations and sustained maneuver land warfare justified this action. Since today no one technology or weapon's platform realistically can achieve this requirement to use historical procurement cost data based upon theoretical first unit cost would be misconstruing to the analysis.

REFERENCES

"AAAV Program Nears Milestone," Marine Corps Gazette, September 1991.

Aaron, H.J., and others, Setting National Priorities, Policy For The Nineties, The Brookings Institution, 1990.

Advanced Assault Amphibious Vehicle (AAAV) Program Office, Preliminary Life Cycle Cost Estimate (LCCE), 11 May 1988.

Advanced Assault Amphibious Vehicle (AAAV) Program Office, Preliminary Life Cycle Cost Estimate (LCCE) Alternatives, 11 May 1988.

Bahnmaier, W.W., Marine Corps Systems Acquisition Management- A Case Study of the LVTP-7 Amphibian Tractor Program, M.S. Thesis, Naval Postgraduate School, Monterey, California, June 1974.

Baker, F.N., Improving Cost Estimating and Analysis in DOD and NASA, Ph.D. Thesis, George Washington University, Washington D.C., 1972.

Beltramo, M.N., and Morris, M.A., Parametric Study of Helicopter Aircraft Systems Costs and Weights, Science Applications Inc., Los Angeles, Ca., 1980.

Batchelder, C.A., and others, An Introduction to Equipment Cost Estimating (RM-6103-SA), The Rand Corporation, Santa Monica, Ca., December 1969.

Corcoran, M.A., An Evaluation of Competitive Procurement Methodologies Applicable to the Advanced Assault Amphibious Vehicle, M.S. Thesis, Naval Postgraduate School, Monterey, California, December 1988.

Fitzgerald, D.M., "Program Manager's Guide", unpublished manuscript presented at the Naval Postgraduate School, Monterey, California, September 1990.

Fox, J.R., and Field, J.L., The Defense Management Challenge Weapons Acquisition, Harvard Business School Press, 1988.

Gaioni, S.A., and Polley, A.C., Parametric Cost Estimation Applied To Marine Corps Medium-Lift Helicopters, M.S. Thesis, Naval Postgraduate School, Monterey, California, December 1990.

Jane's All The World's Armor Vehicles, Jane's All The World's Armor Vehicles Publishing Company Limited, 1990-1991.

Jane's All The World's Fighting Ships, Jane's All The World's Fighting Ship's Publishing Company Limited, 1988.

Kusek, L.J., Life-Cycle Costs of Advanced Amphibious Assault System Candidates (CRM 90-253), Center for Naval Analyses, January 1991.

Kusek, L.J., Research Memorandum LVT(X) Independent Cost Estimate (ICE), Center for Naval Analyses, August 1984.

Large, J., and others, Cost Estimates and Estimating Procedures in the 11R Maverick and AMRAAM Programs, Rand Corporation, 1988.

Miller, B.M., and Soverign, M.G., Parametric Cost Estimating with Applications to Sonar Technology, Naval Postgraduate School, Monterey, California, September 1973.

Nichols, T., and Rossi, R., U.S. Weapon Systems Costs 1988-1991, Data Search Associates, 1988-1991.

Parametric Cost Estimating Relationship Module Manual, DAI Inc., September 1990.

Stewart, R.D., and Wyskida, R.M., Cost Estimators Reference Manual, John Wiley and Sons Inc., 1987.

Seal, T.E., and Bierly, J.F., "Over-the Horizon Amphibious Operations," Marine Corps Gazette, July 1991.

INITIAL DISTRIBUTION LIST

Commandant of the Marine Corps Code TE 06 Headquarters, U.S. Marine Corps Washington, D.C. 20360-0001	2
Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
Library, Code 0142 Naval Postgraduate School Monterey, California 93943-5002	2
Dr. Joseph San Migel Department of Administrative Sciences Naval Postgraduate School Monterey, California 93943-5002	2
Capt. Norman Peters 283 Aristides Street Palm Harbor, Florida 34683	2
Dr. Michael G. Sovereign Department of Operations Research Naval Postgraduate School Monterey, California 93943-5002	2